NASA Occupational Health Conference—2005

Laser Bioeffects

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Laser Hazards

- Potential for serious injury
- Low probability for exposure
- Serious retinal injuries occur most frequently from short-pulse laser exposures
  - when eye protectors ignored

Laboratory Accidents

- Most eye injuries have occurred in research and engineering laboratories. Why?
- Open beams
  - During alignment
  - For flexibility in calibration procedures
  - Experimental changes in setup
- “I know where the beam is!” (Famous last words)

Guidelines for Human Exposure

- American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs) (…since 1968)
- ICNIRP Guidelines for human exposure to laser radiation (2001)
- ANSI Z136.1-2000, paragraph 8
- All exposure limits are generally the same (minor differences for CW lasers)

National Consensus Standard for Safe Use of Lasers

- *American National Standard for the Safe Use of Lasers,*
  ANSI Z136.1-2000

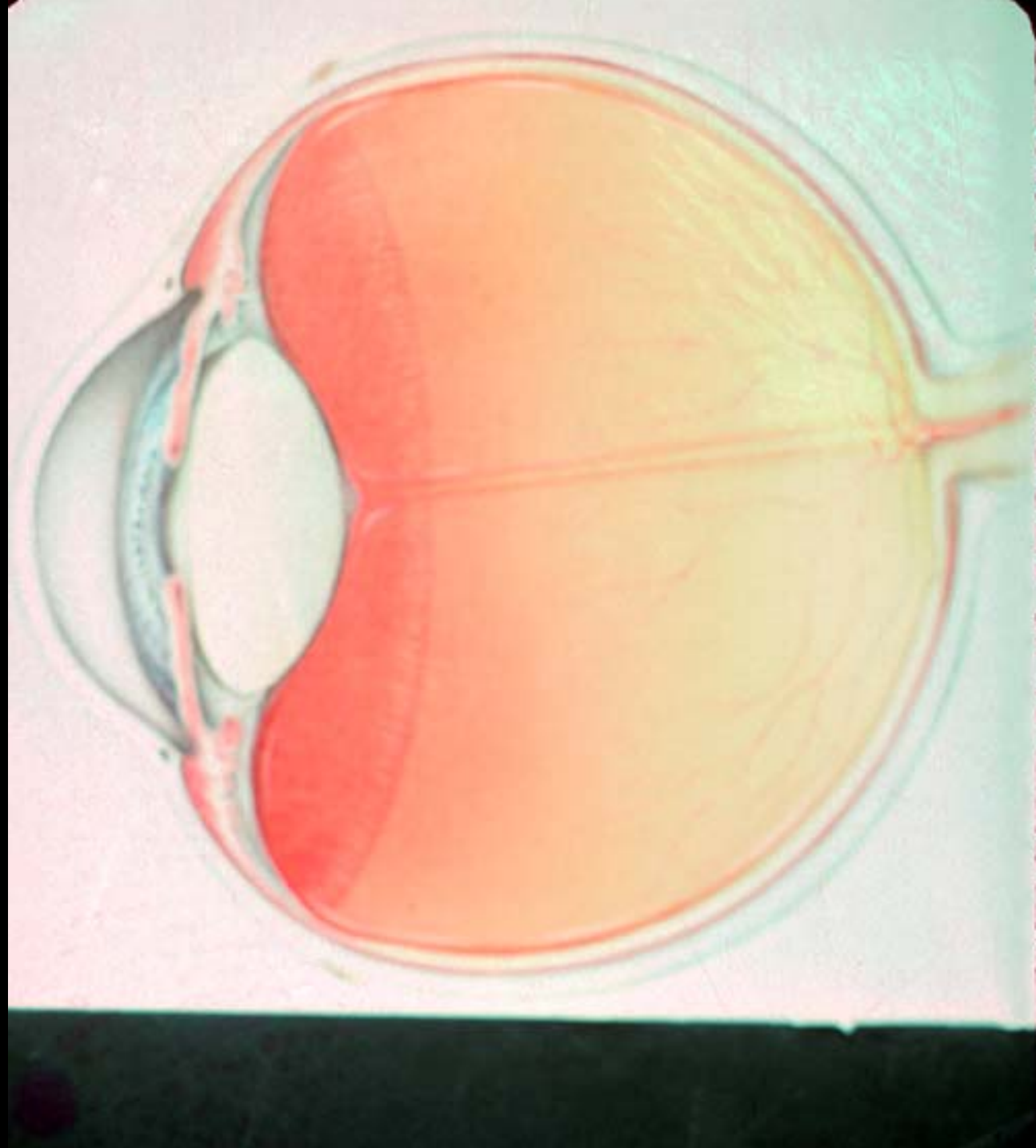
- Secretariat (publisher): Laser Institute of America (LIA), Orlando

ANSI Z-136.1-2006(?)
Safe Use of Lasers

- Update of ANSI Z136.1-2000 has been underway for four years.
- New hazard Classes 1M and 2M and change of Class 3A to 3R.
- Approval of the final document in Standards Sub-Committee. Now in final edit for main vote
- *Major change* in Medical Surveillance—Change "shall" to "should" for pre-placement exams

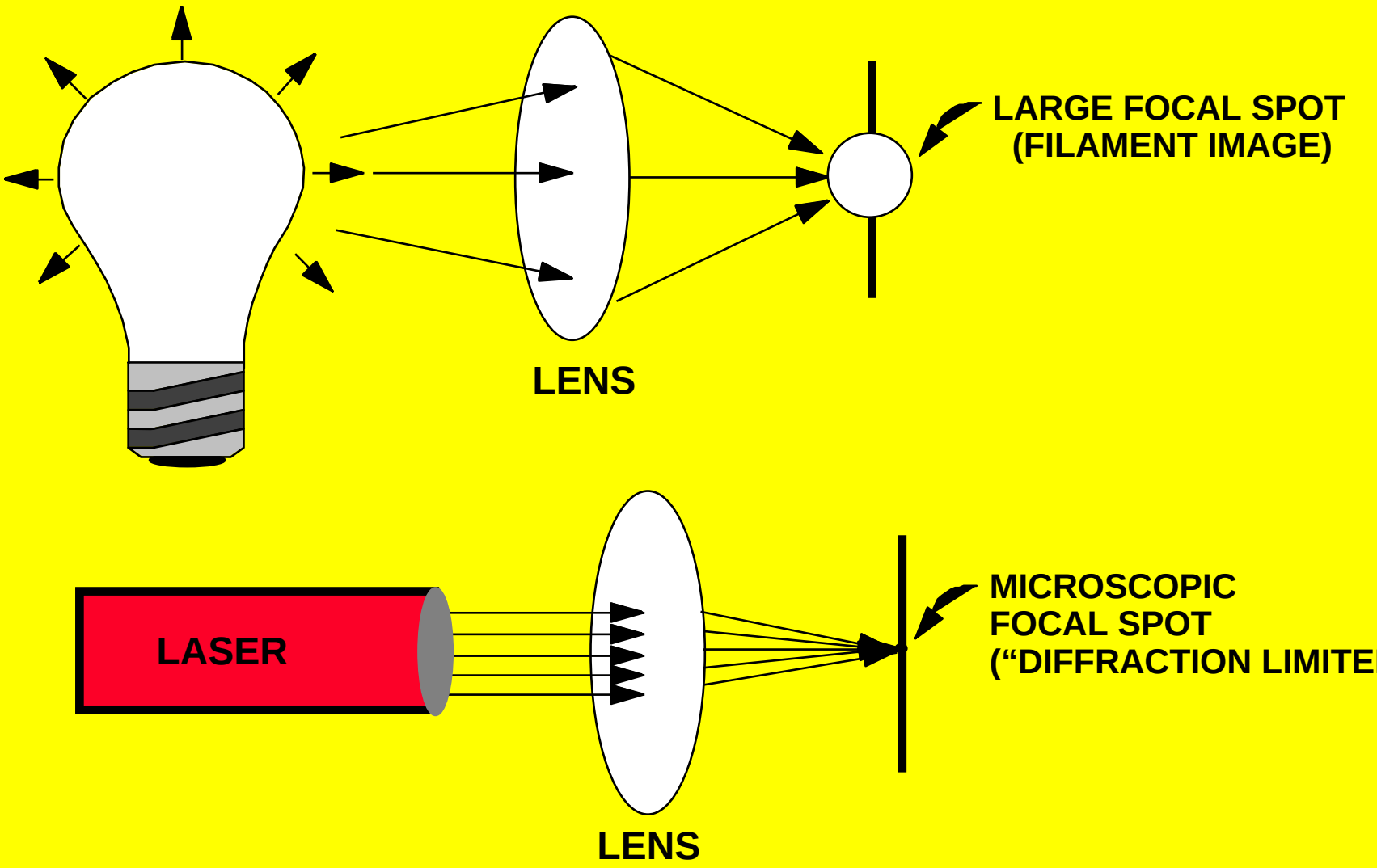
Human Eye

- The principal target organ
- About 25 mm diameter
- Pupil is only 2-7 mm diameter



Why is a laser so hazardous?

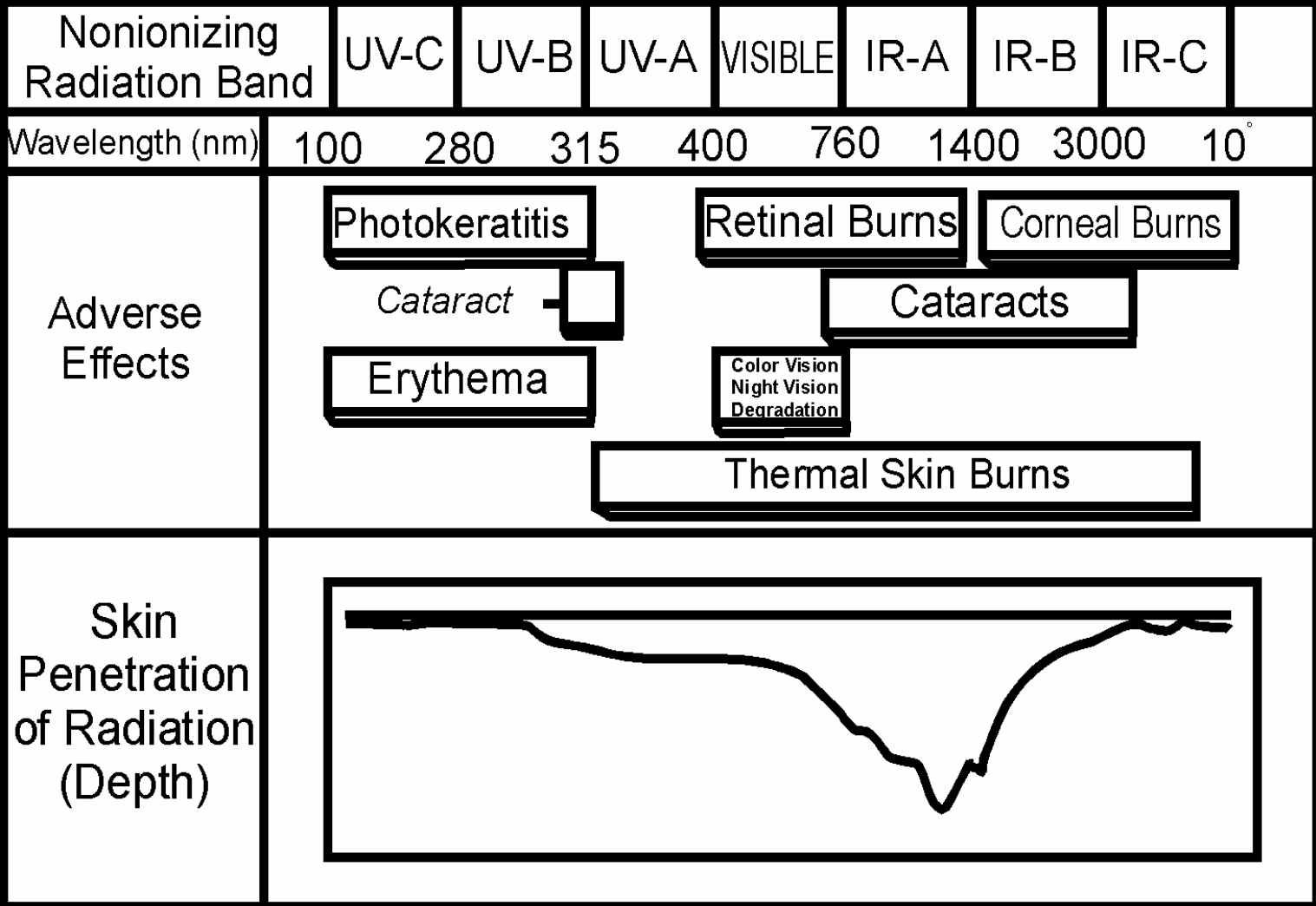
- From optical physics, the answer is: “radiance”
  - …but what is that?
- Radiance is the physical quantity we know as “brightness”
- Even a 1-mW laser pointer is 10X brighter than the surface of the sun!
- It can therefore be focussed to an exquisitely small spot (as for surgery)…or within the eye!



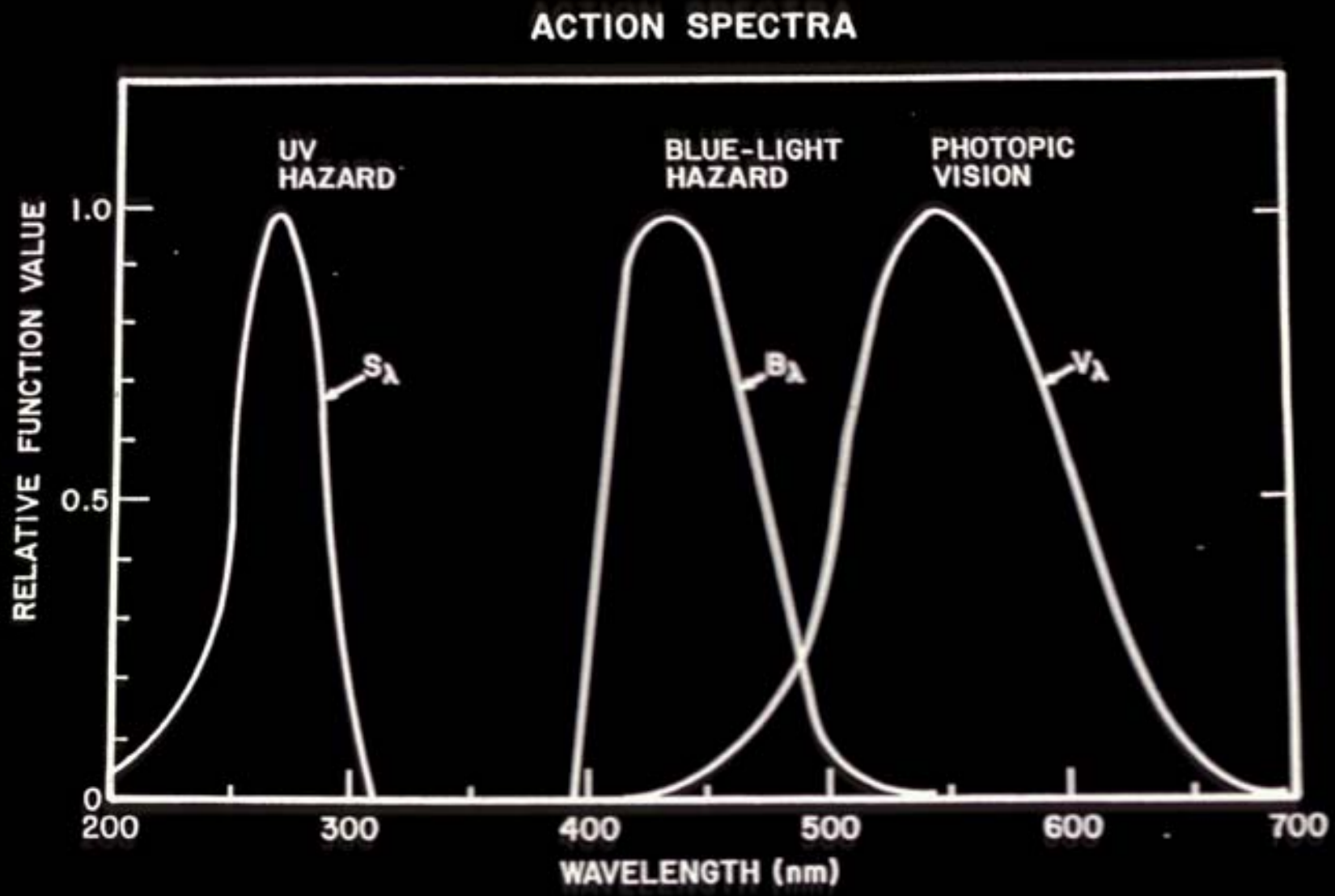
From Sliney DH and Trokel, S, 1993

The CIE Photobiological Spectral Bands

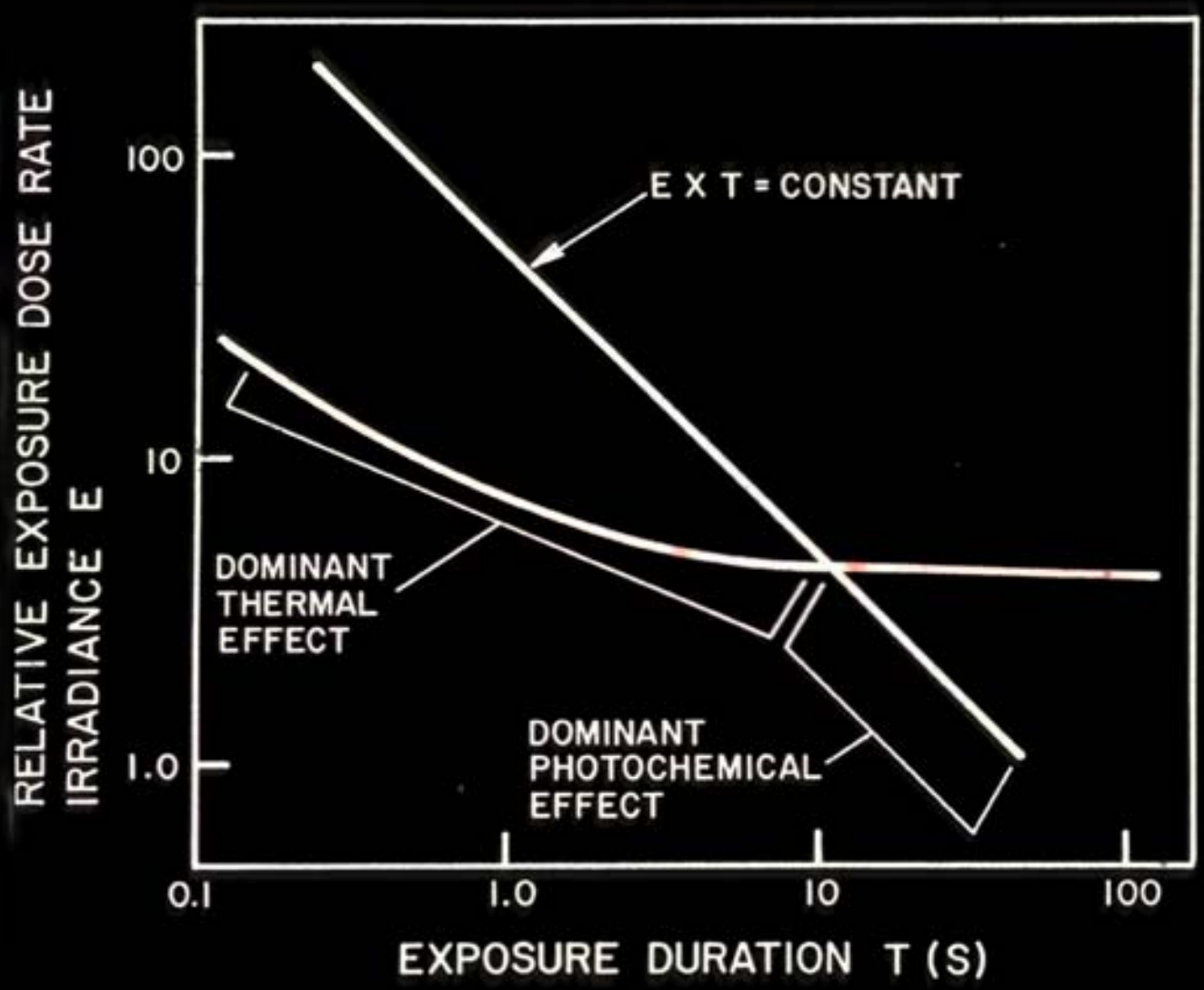
Photobiological Effects



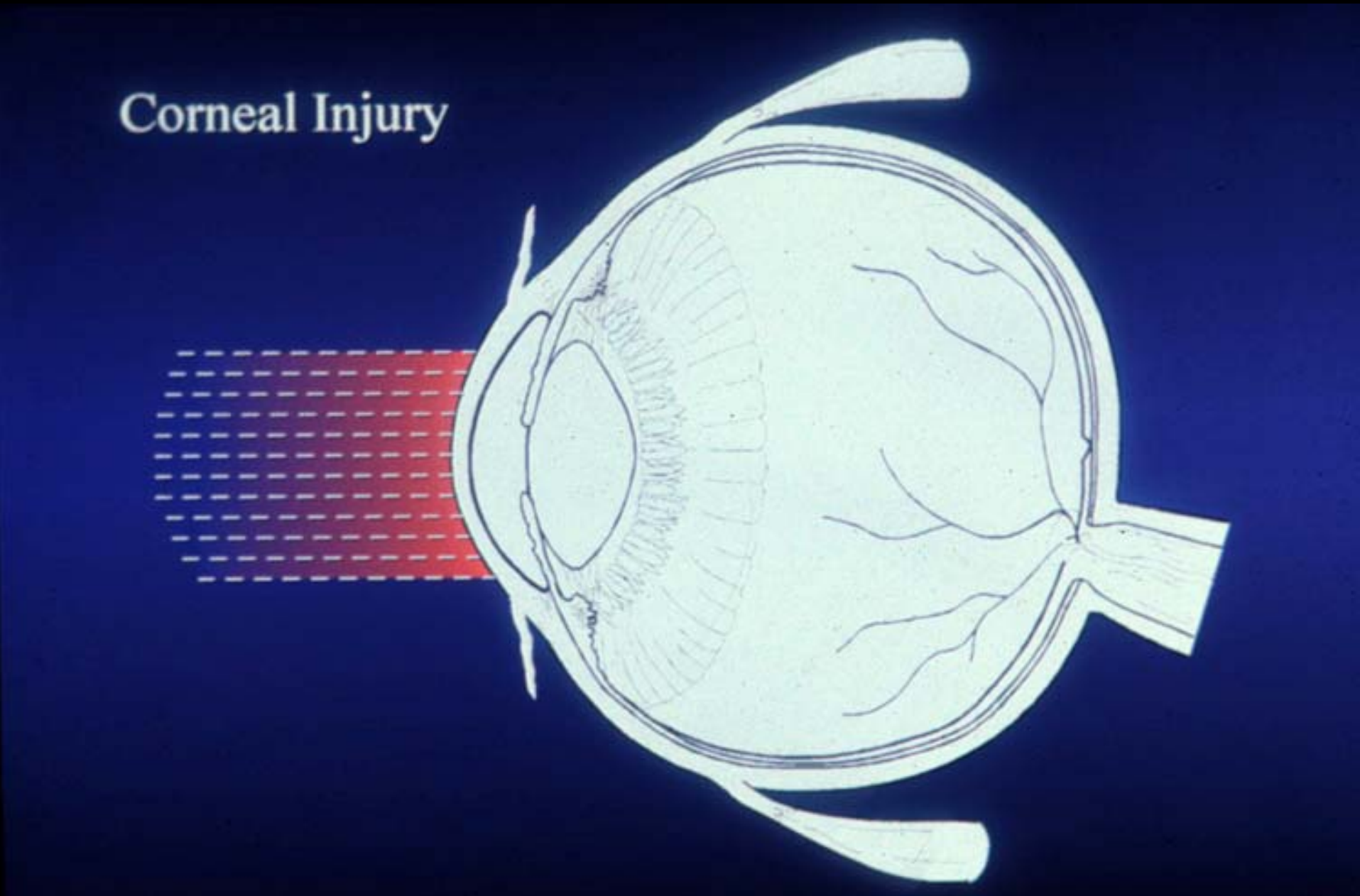
Photochemical Damage Mechanisms

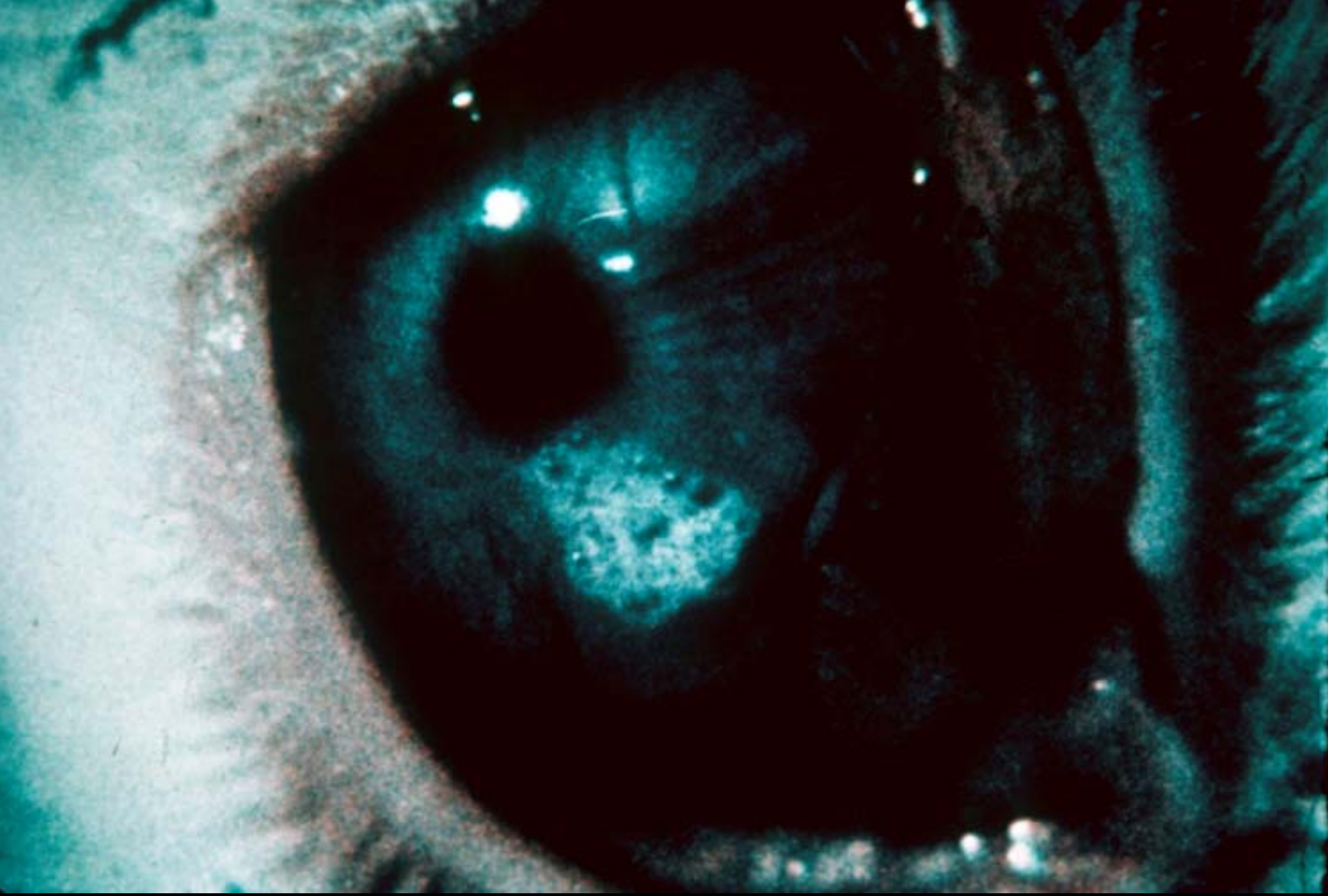


Thermal and Photochemical Mechanisms

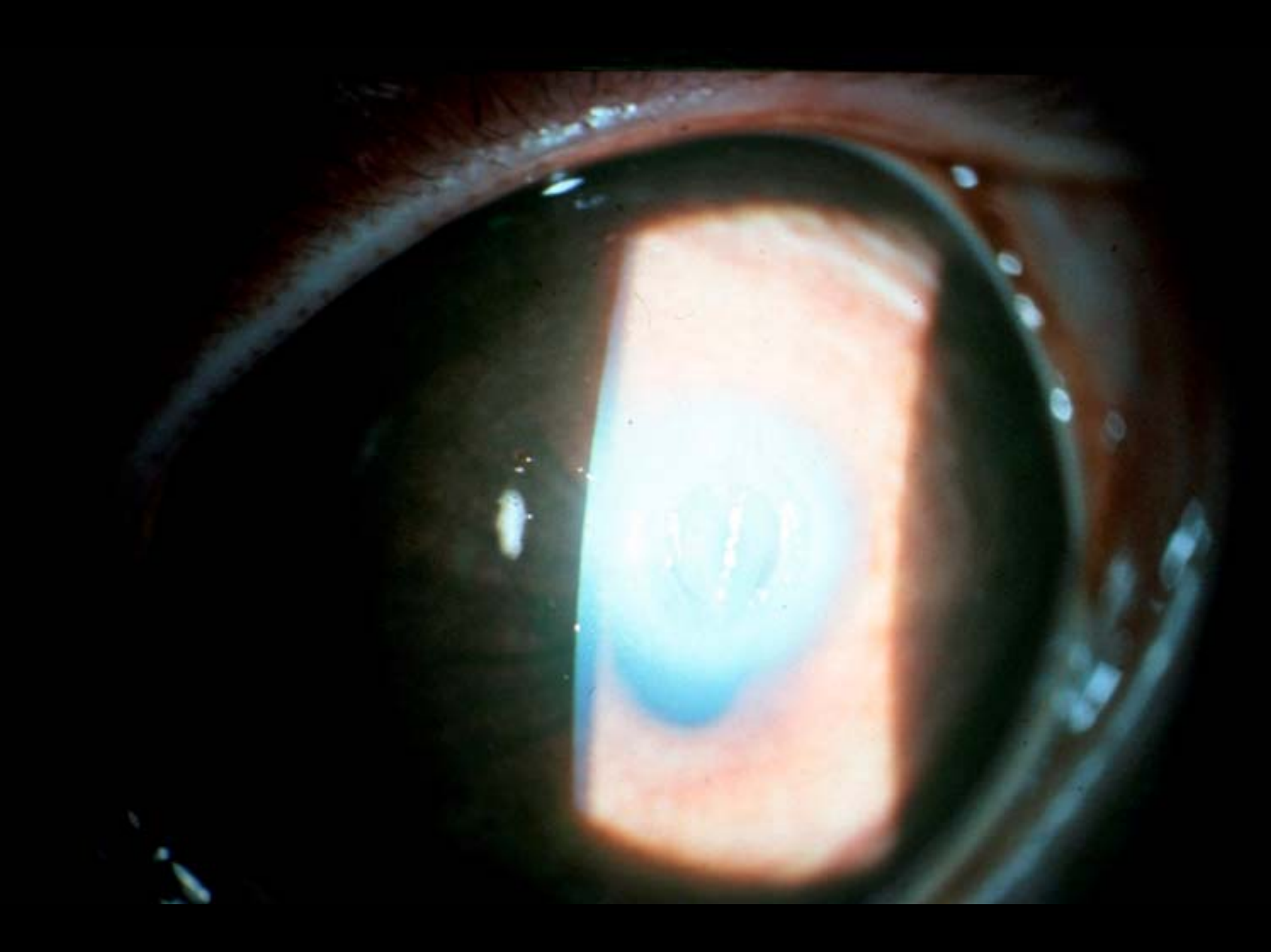


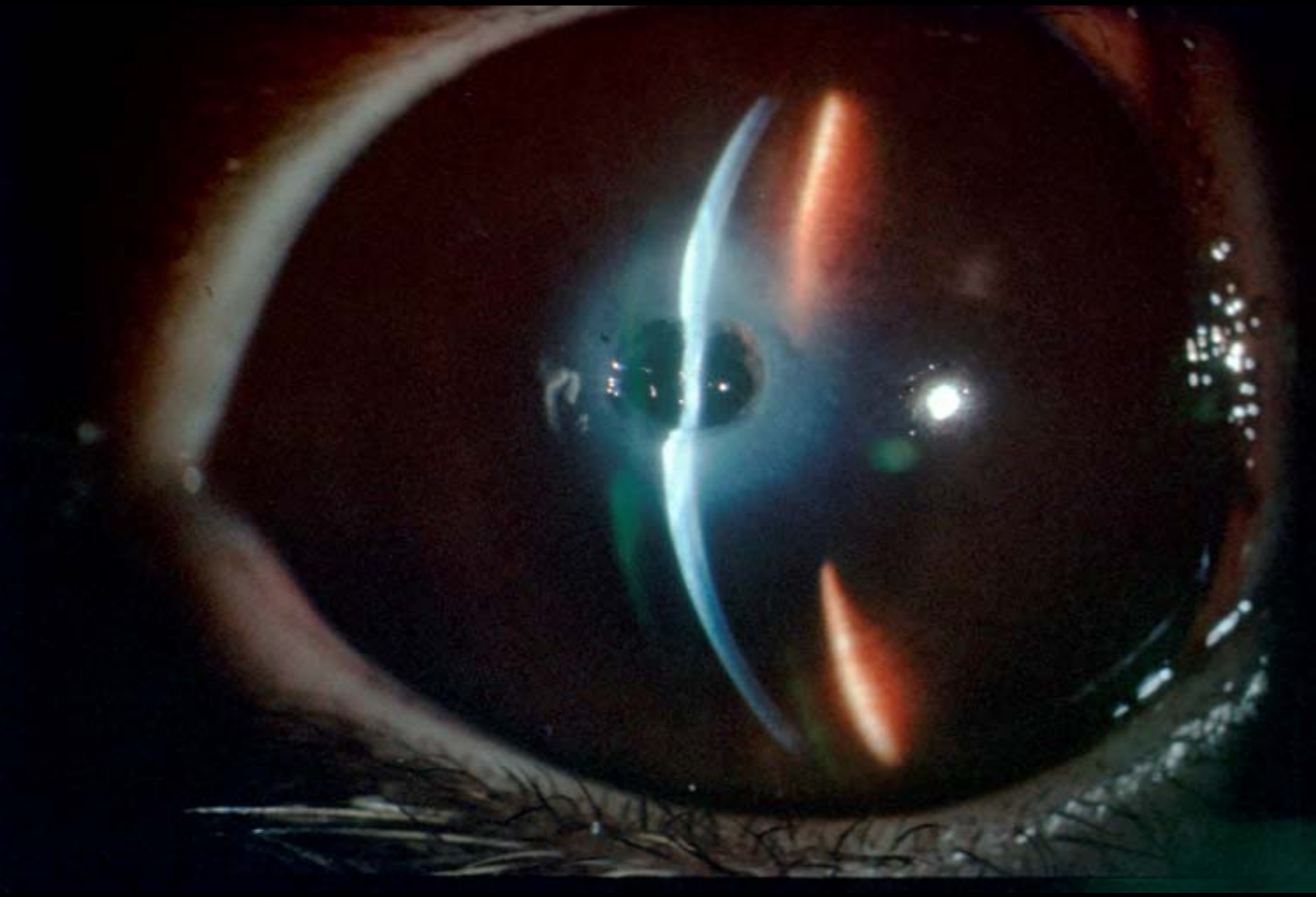
Corneal Hazards: UV-B/C, IR-B, IR-C

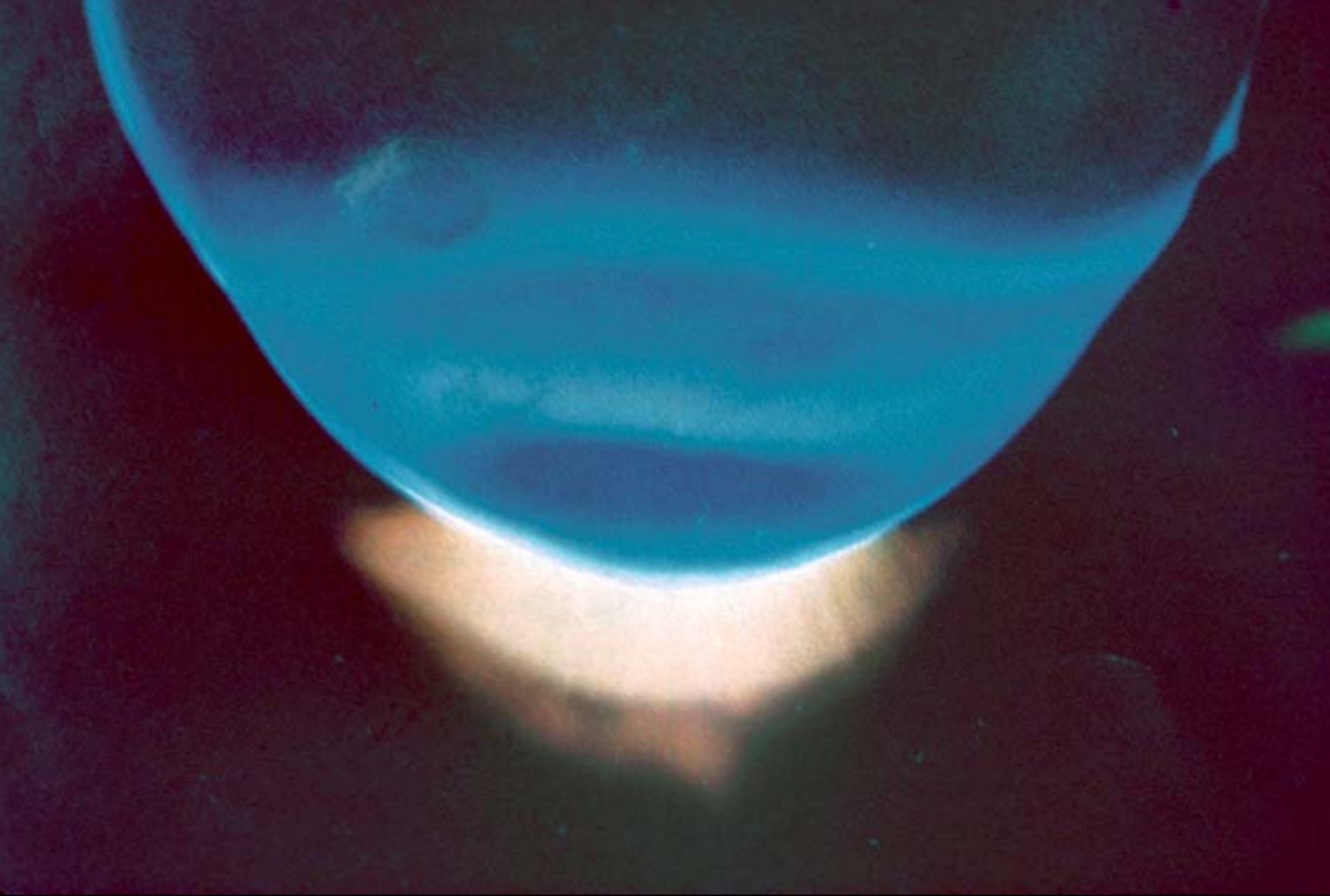




Superficial corneal lesion -- will clear in 24-48 h

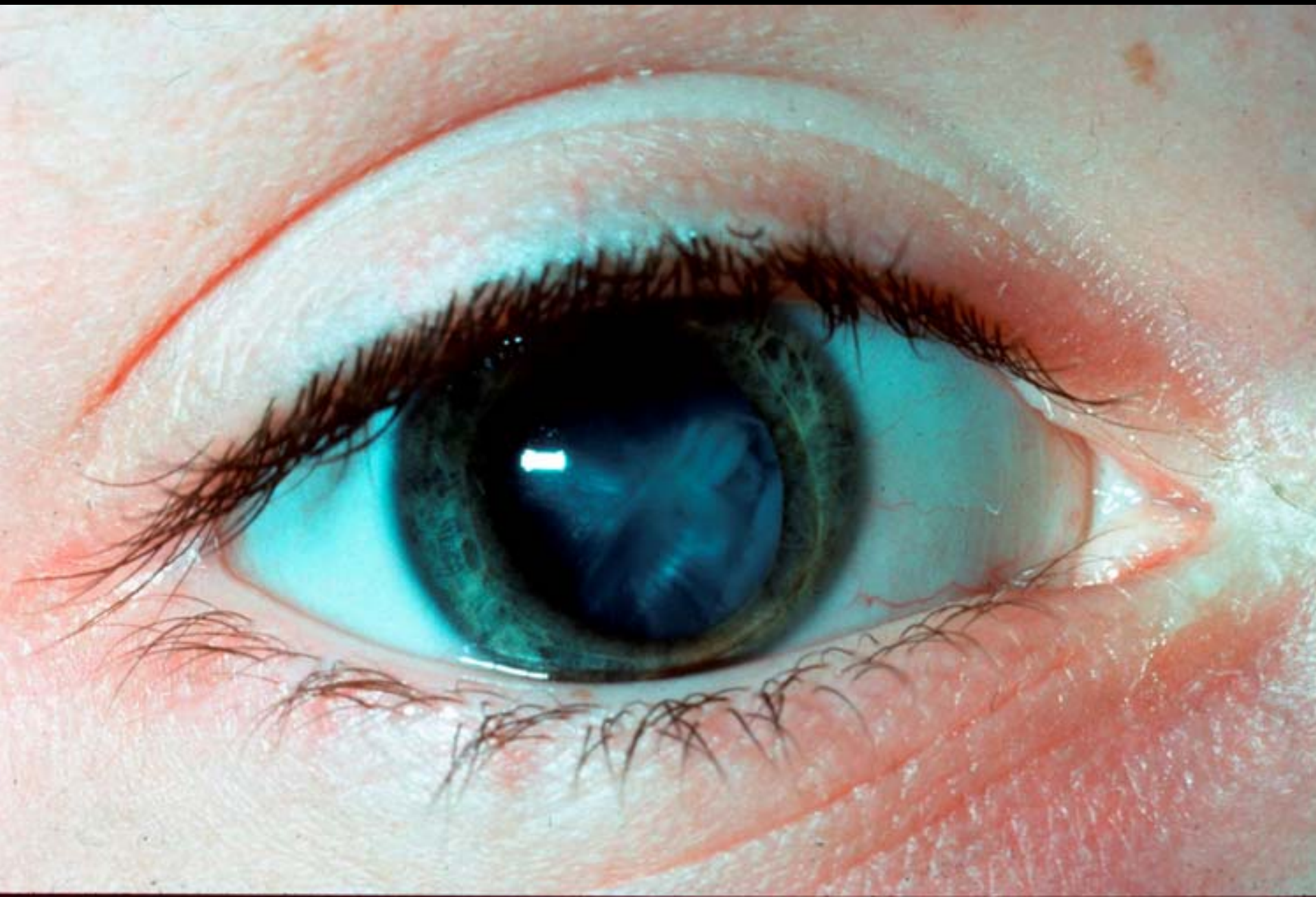




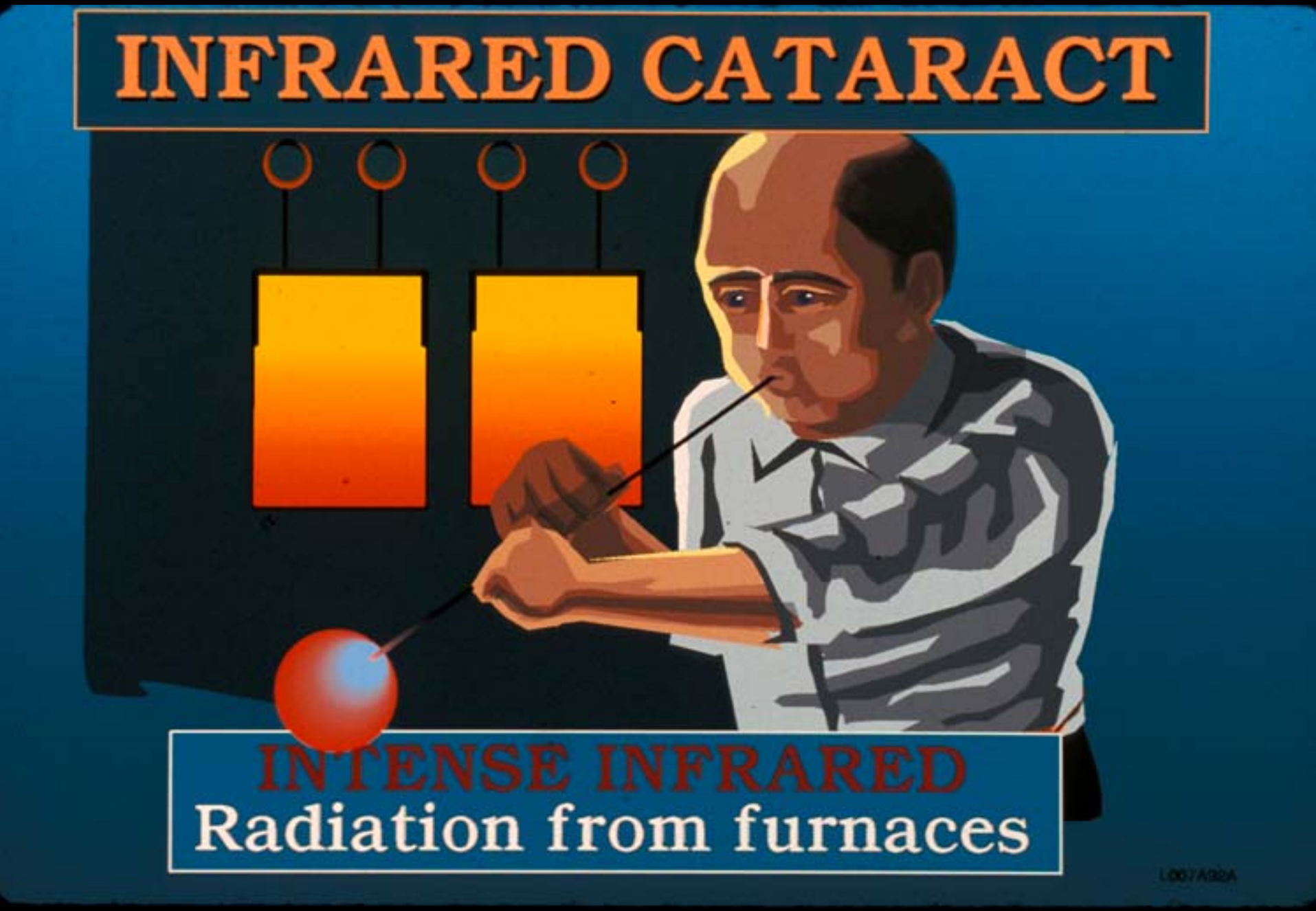


Pulsed-laser corneal ablation—the impact of penetration depth

Cataract - More than 1 million cases in the USA / year



INFRARED CATARACT

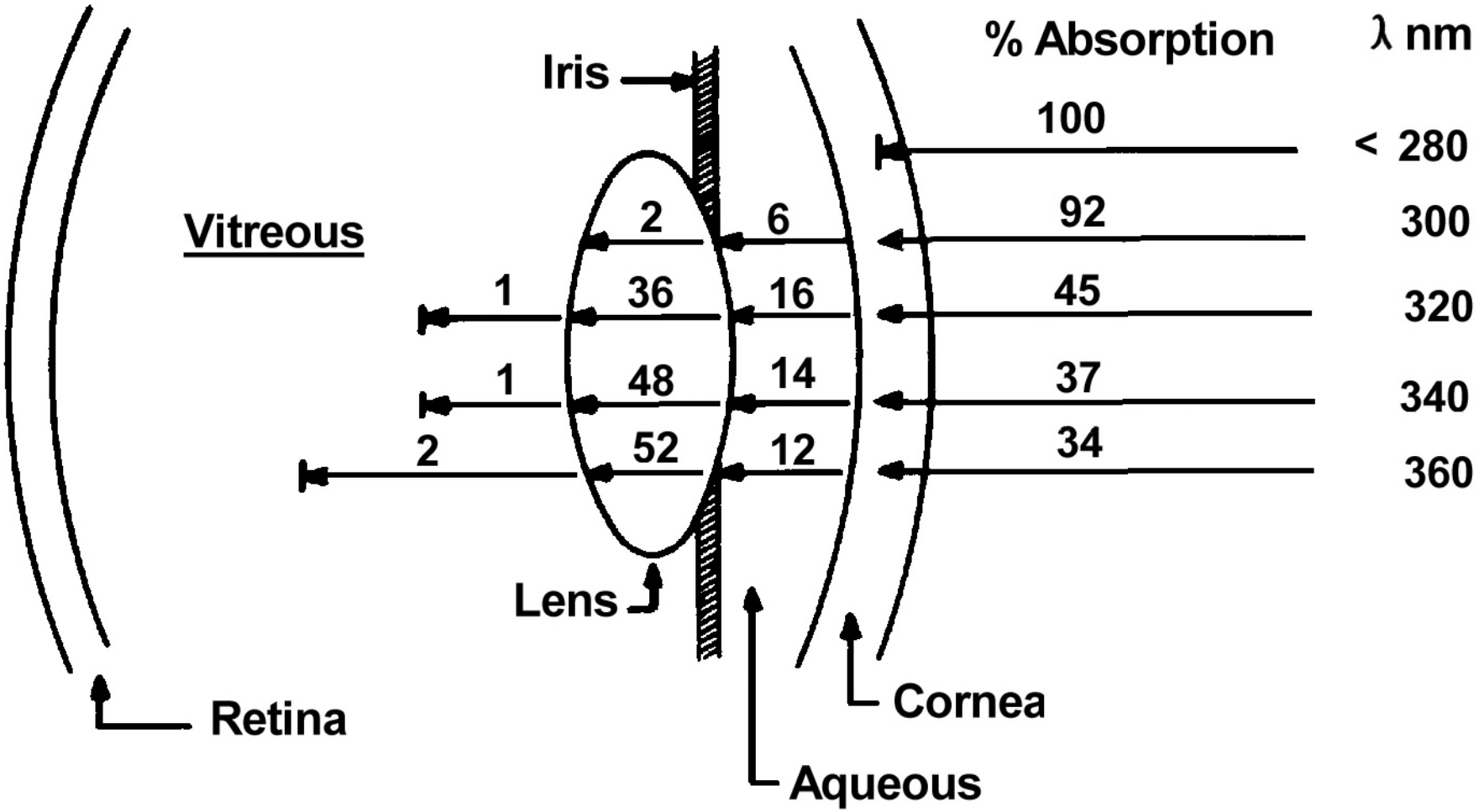


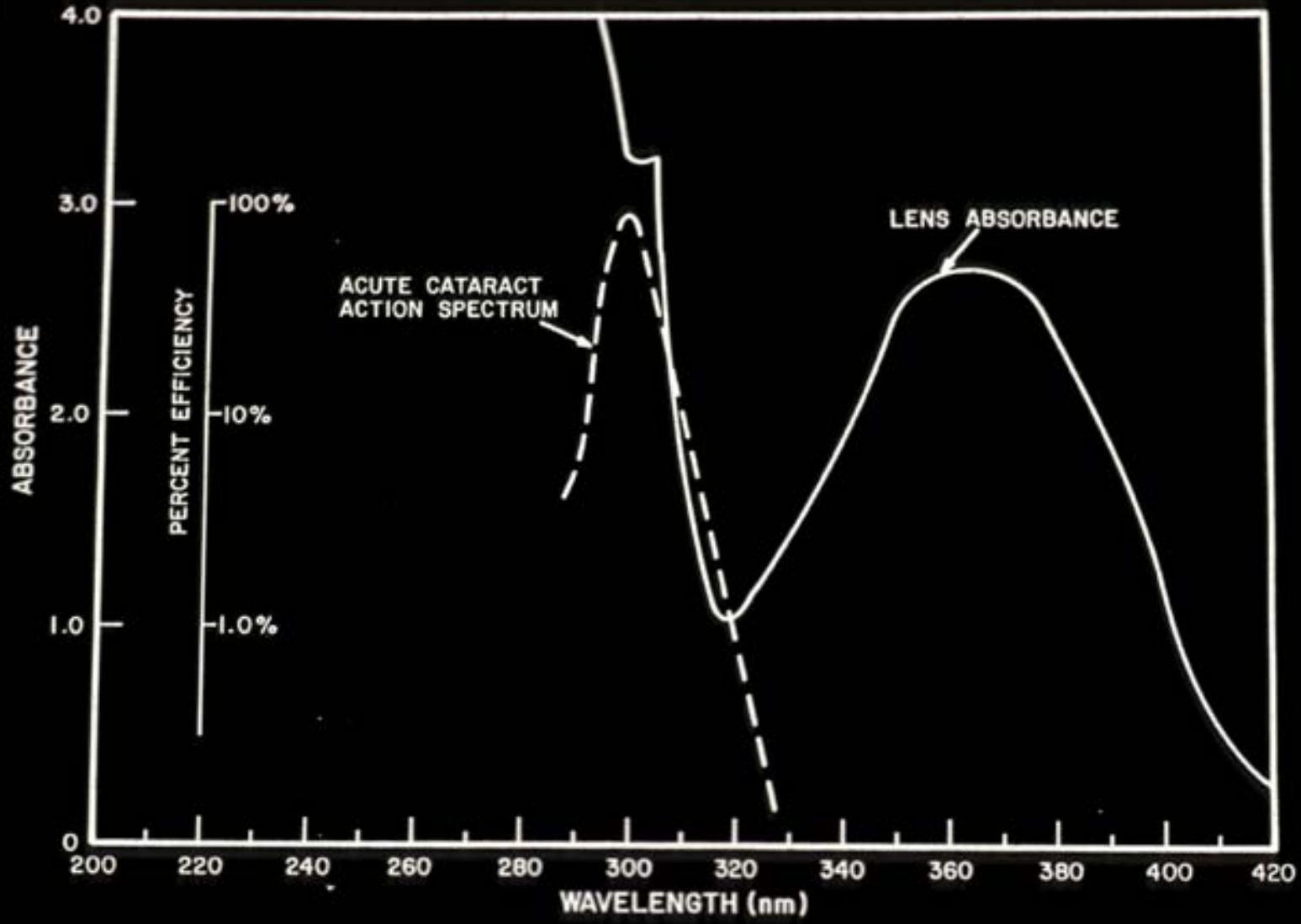
INTENSE INFRARED
Radiation from furnaces

Infrared Cataract

- IR-A and IR- B (780 nm - 3,000 nm)
- “Glassblower’s Cataract” with exfoliation of the lens is now quite rare
- Work conditions were far more severe in 1800-1930 in hot industries
- Dr. Eva Lydahl (1984) showed a higher incidence of early onset of cataract in Swedish glass workers but not steel workers

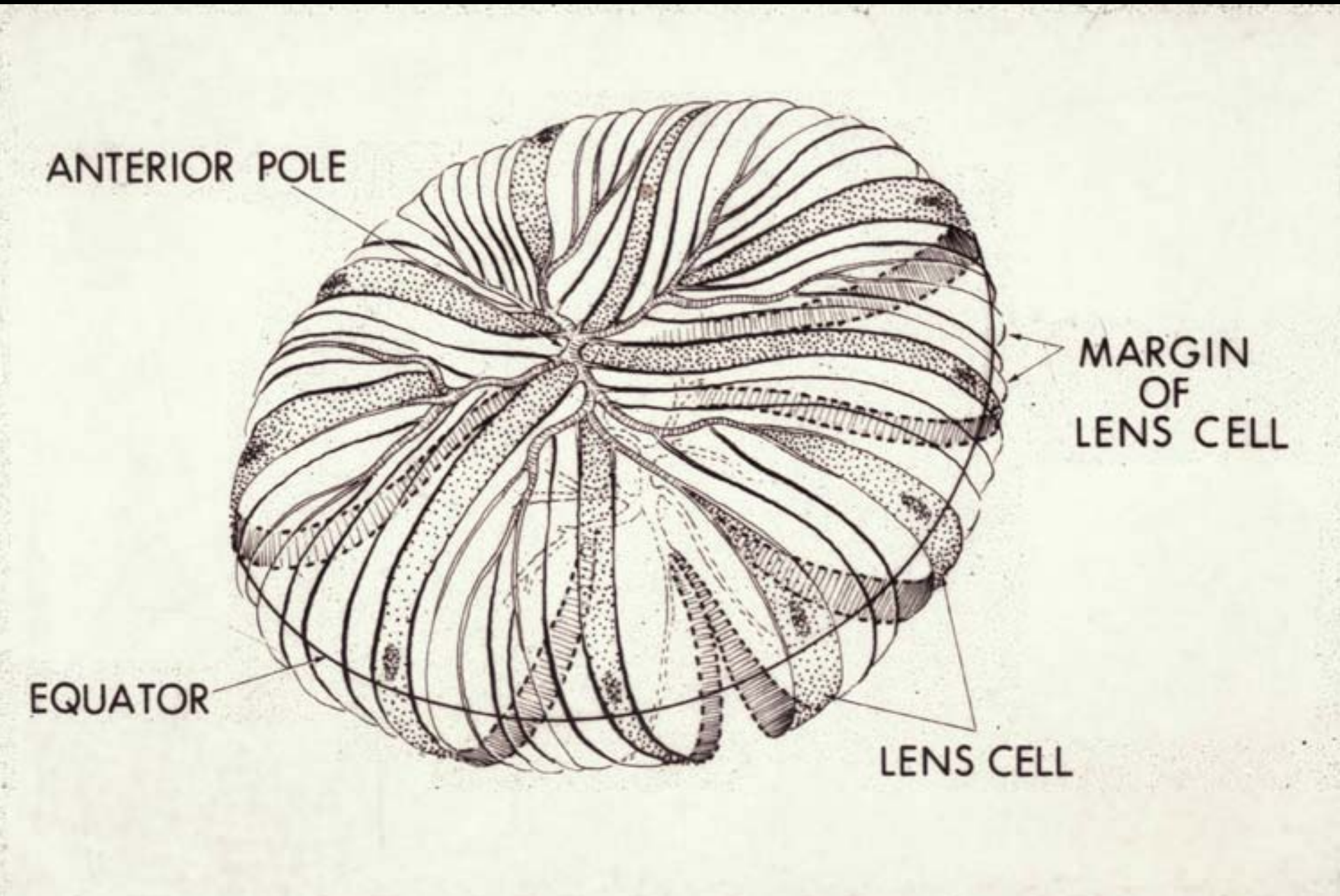
UV Spectral Absorption in Ocular Tissue



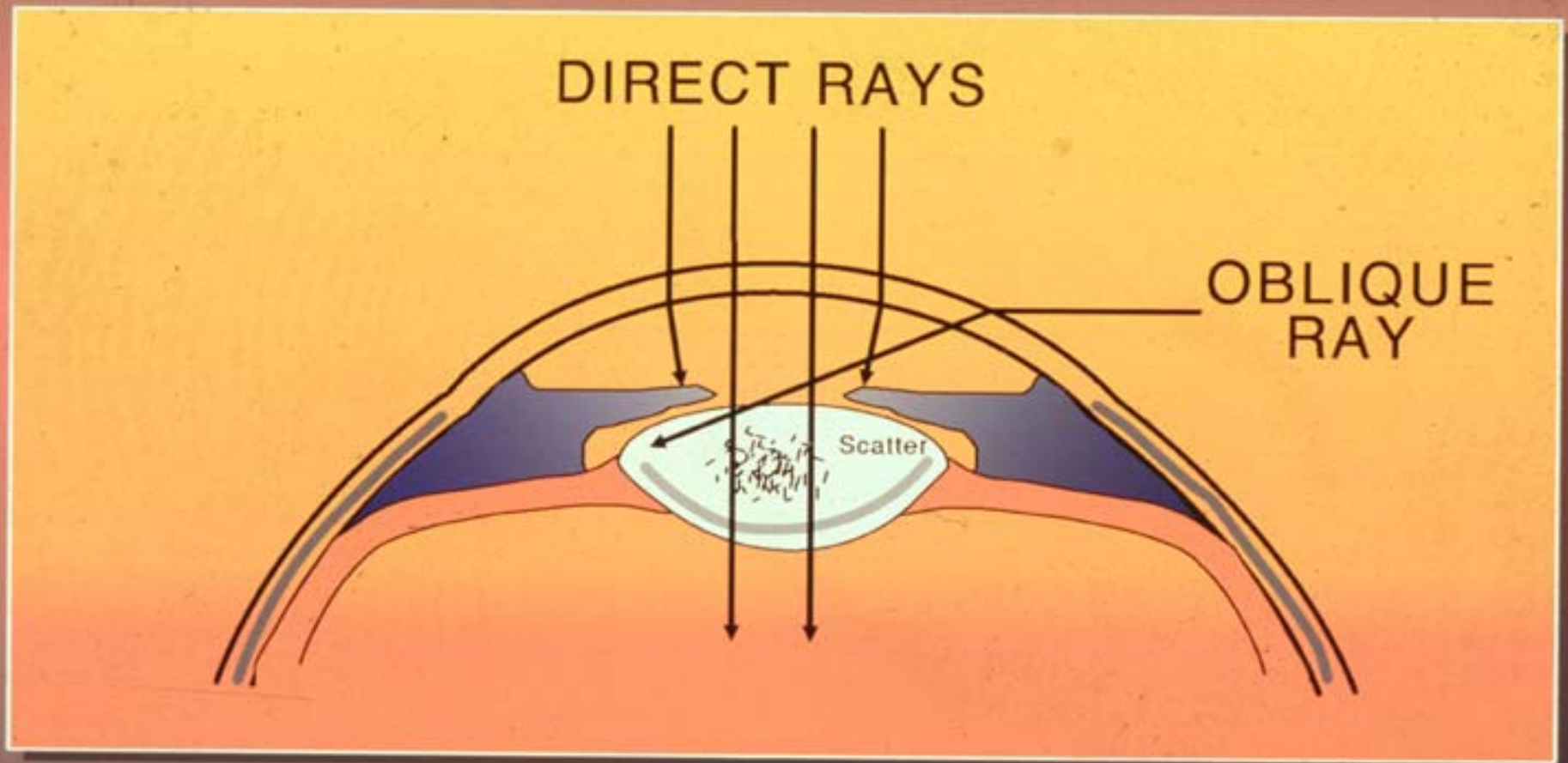


Action spectrum for cataract in an animal model--a 10 nm bandwidth

Anatomy of the Crystalline Lens



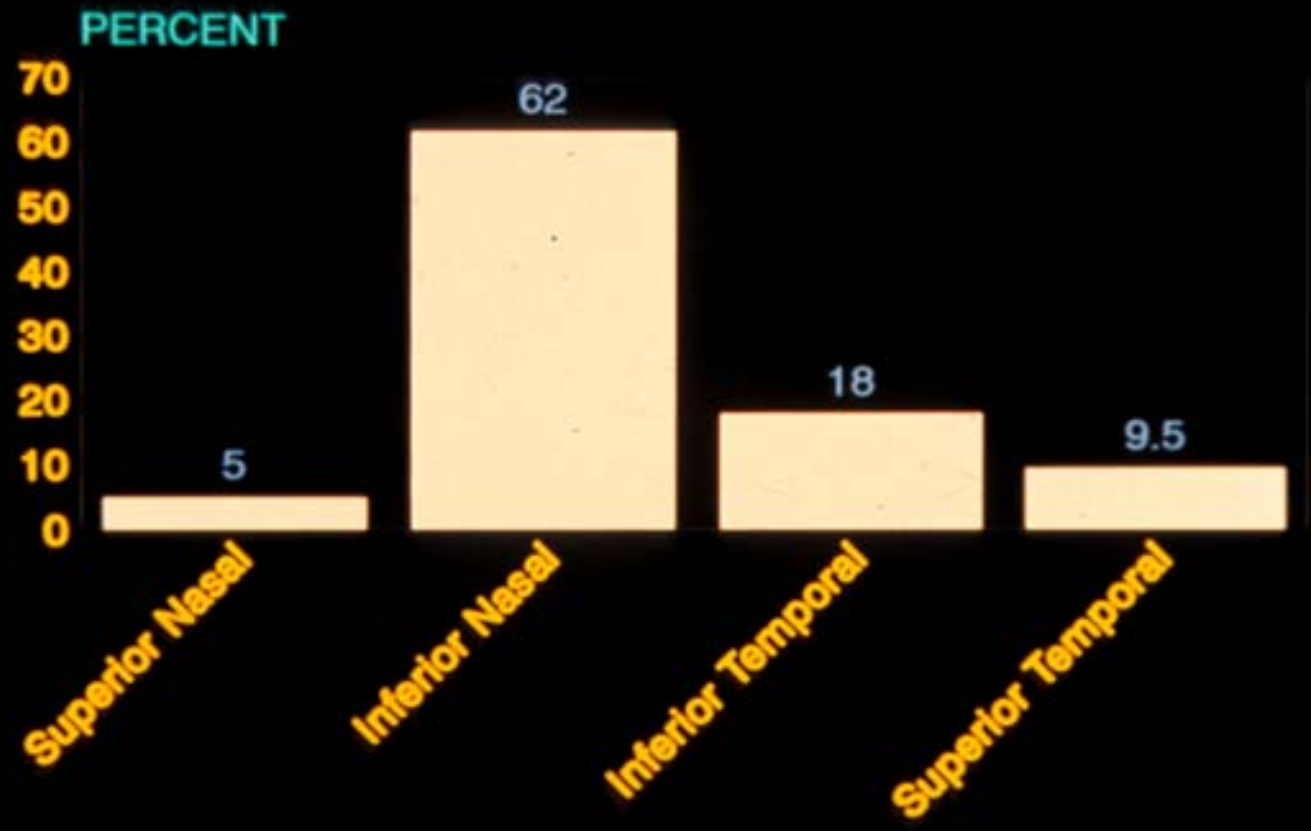
THE CORONEO EFFECT



DHS
USACHPPM
1995

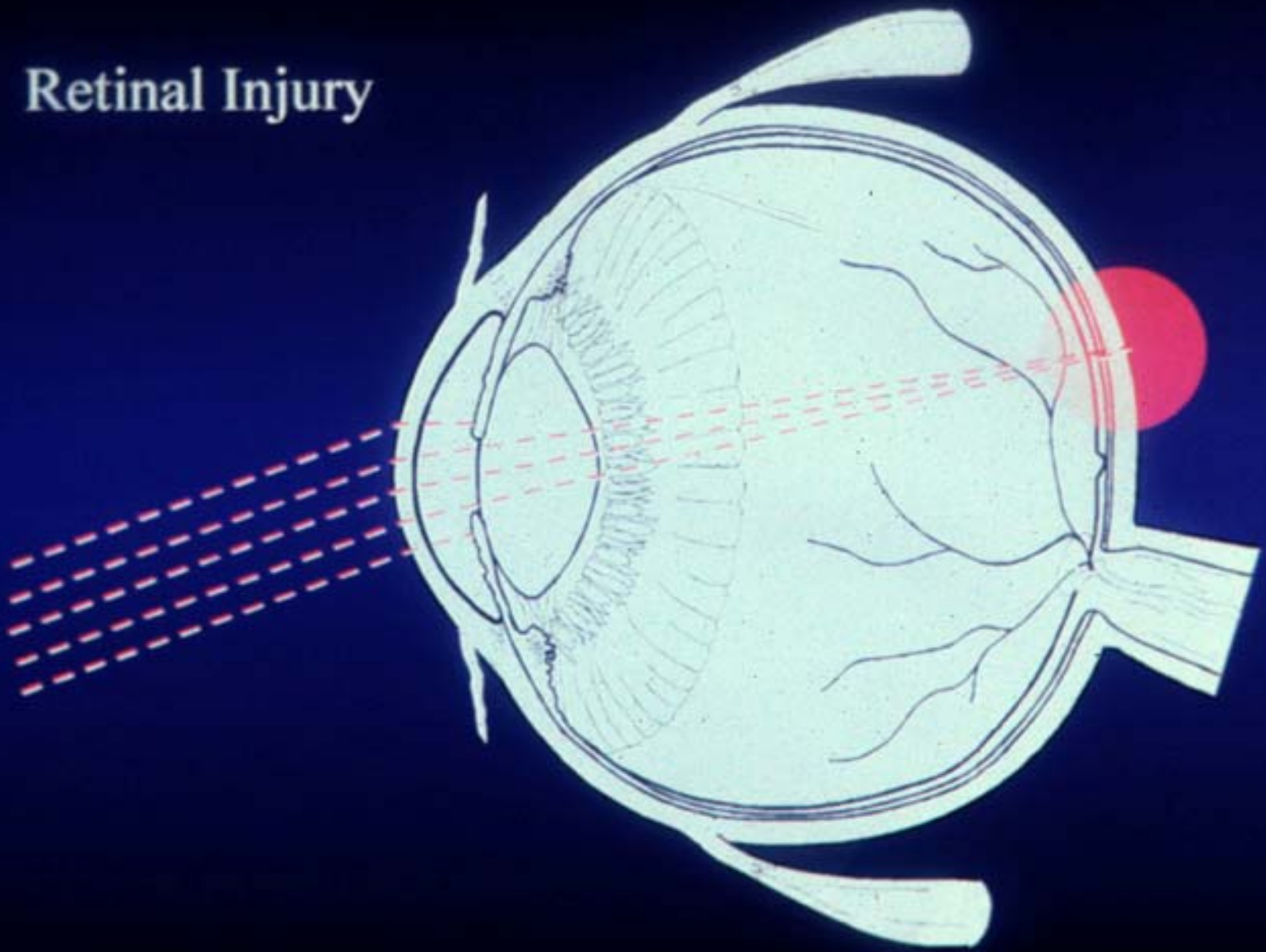
Distribution of Cortical Cataract by Segment

Data from the Beaver Dam Study



Am J Pub Hlth, 82(12):1658-1662 (1992)

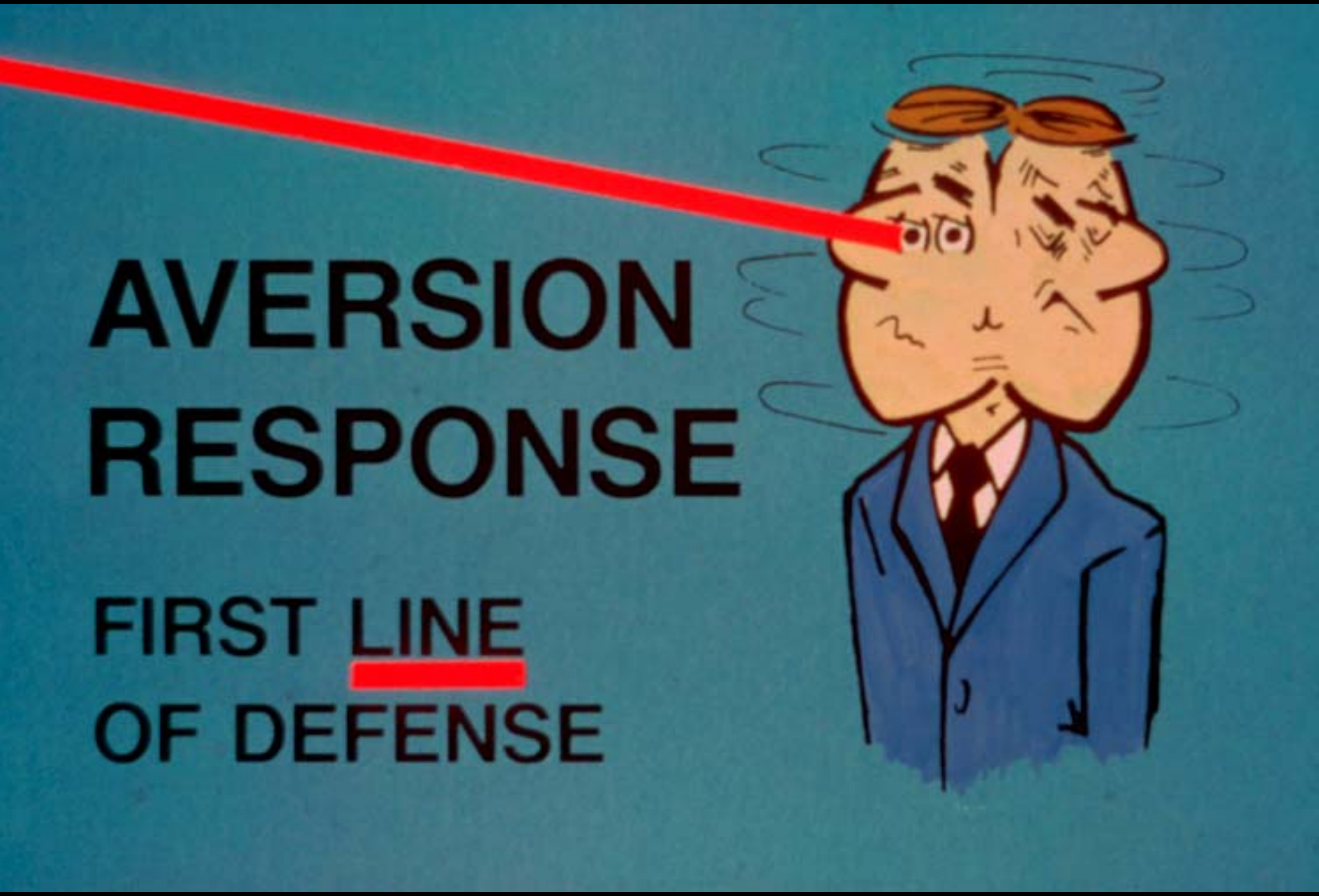
Retinal Injury



A laser pointer is 10X brighter than the sun

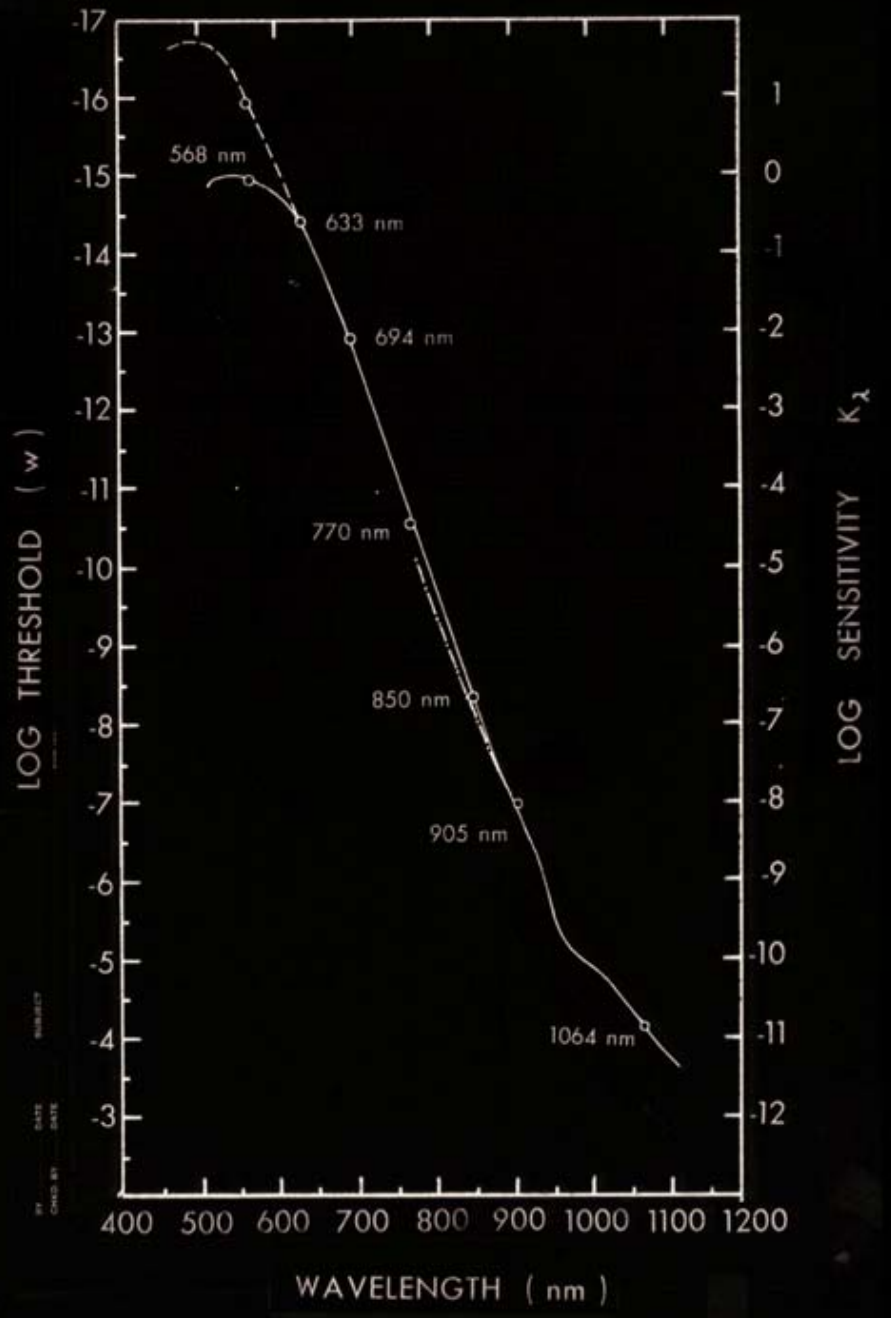
AVERSION RESPONSE

FIRST LINE OF DEFENSE

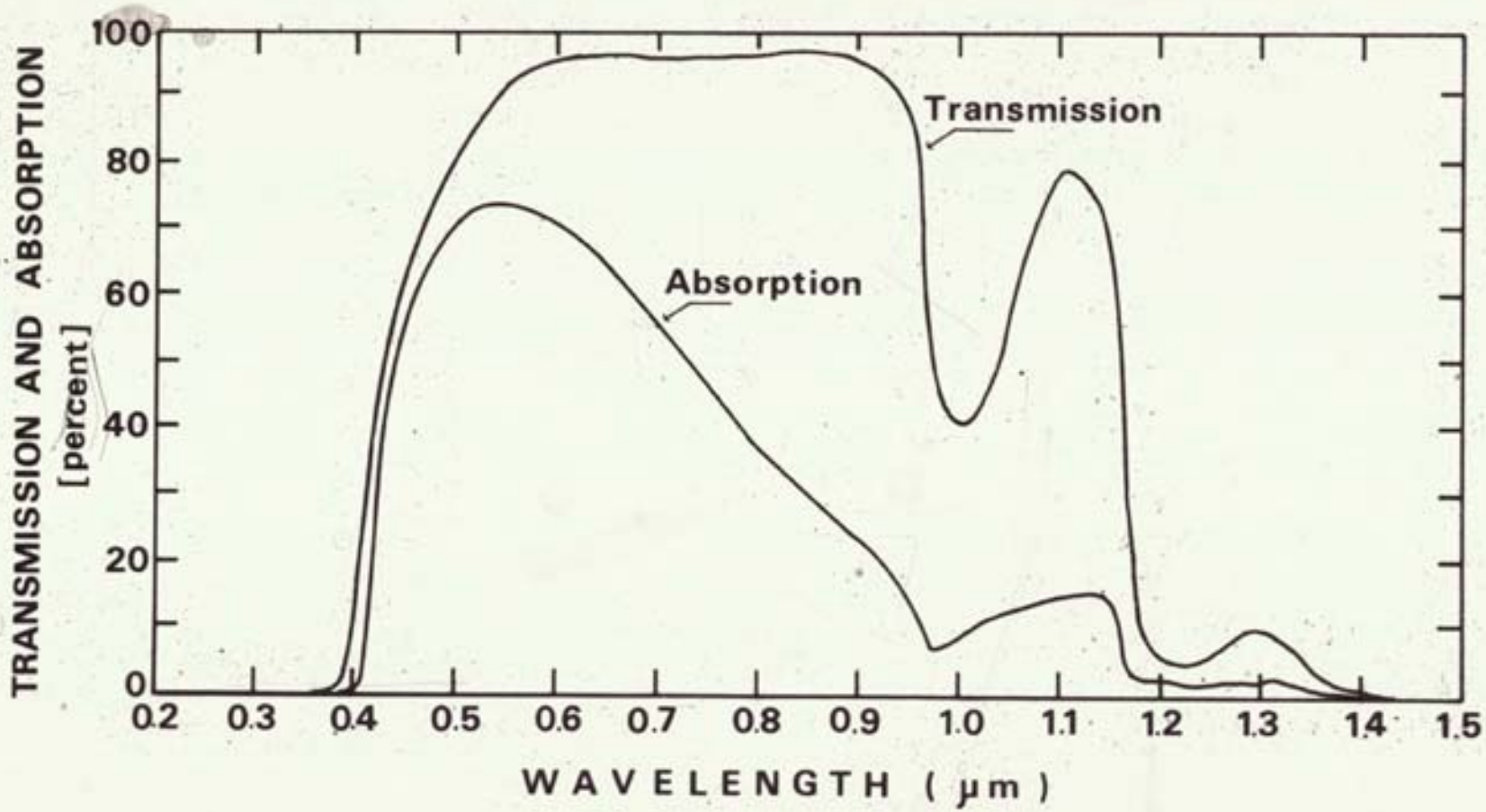


Spectral Response of Daylight Vision

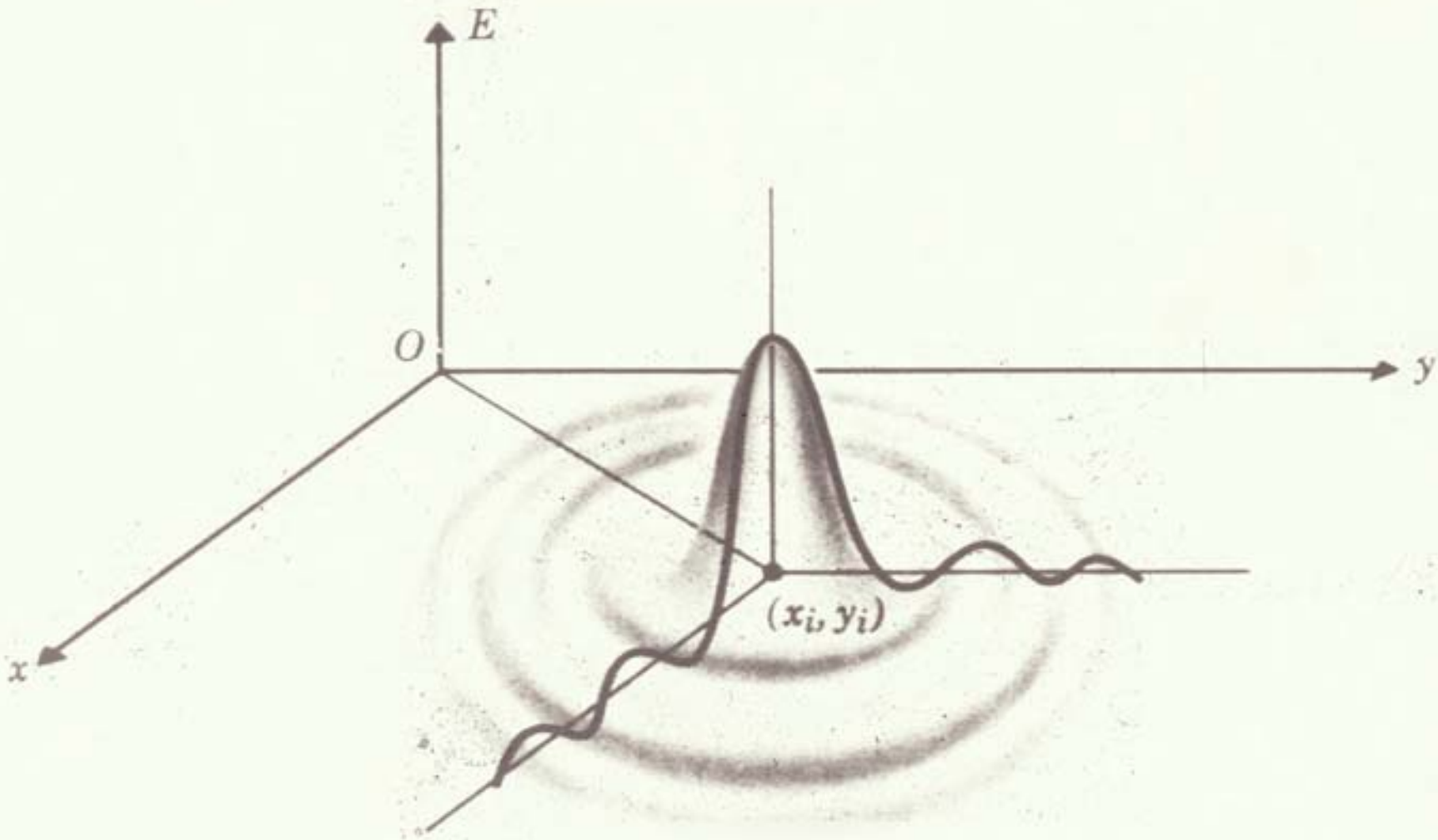
- Logarithmic plot shows spectral dependences of photopic (cone) threshold over 14 orders of magnitude
- Even the 1064-nm Nd:YAG laser wavelength can be seen—but at levels close to the exposure limit



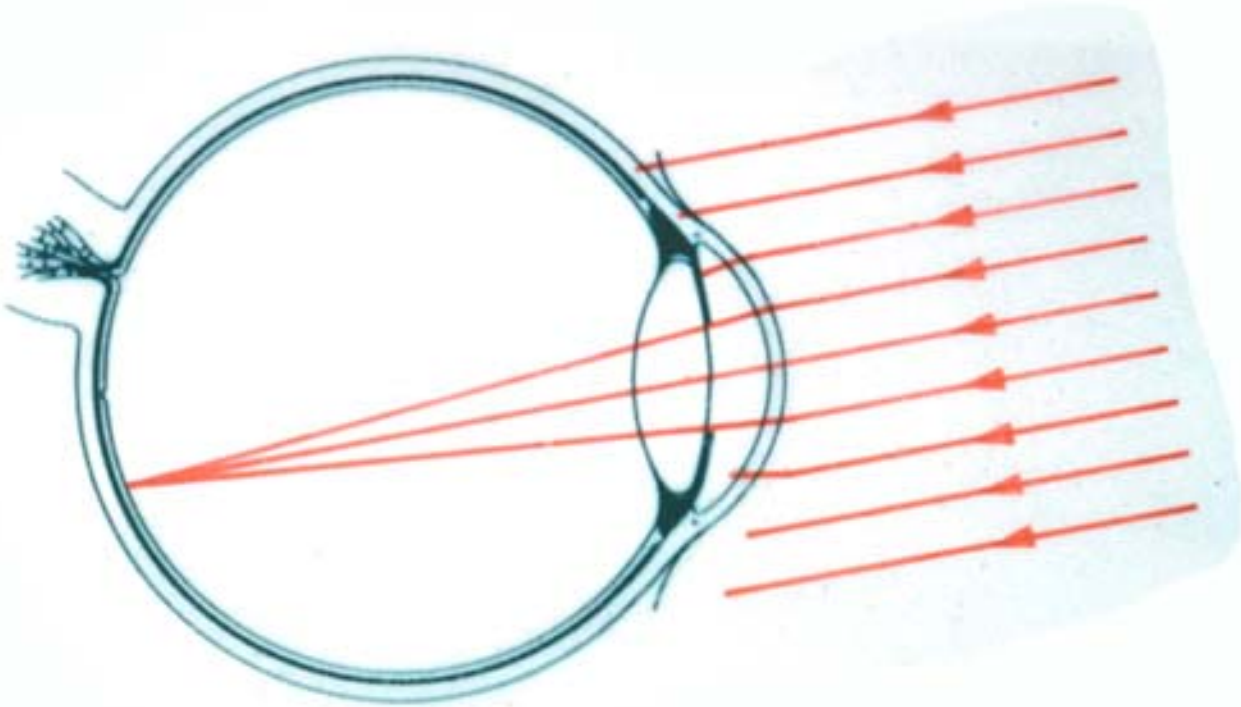
The Retinal Hazard Region” ~ 400 to 1400 nm



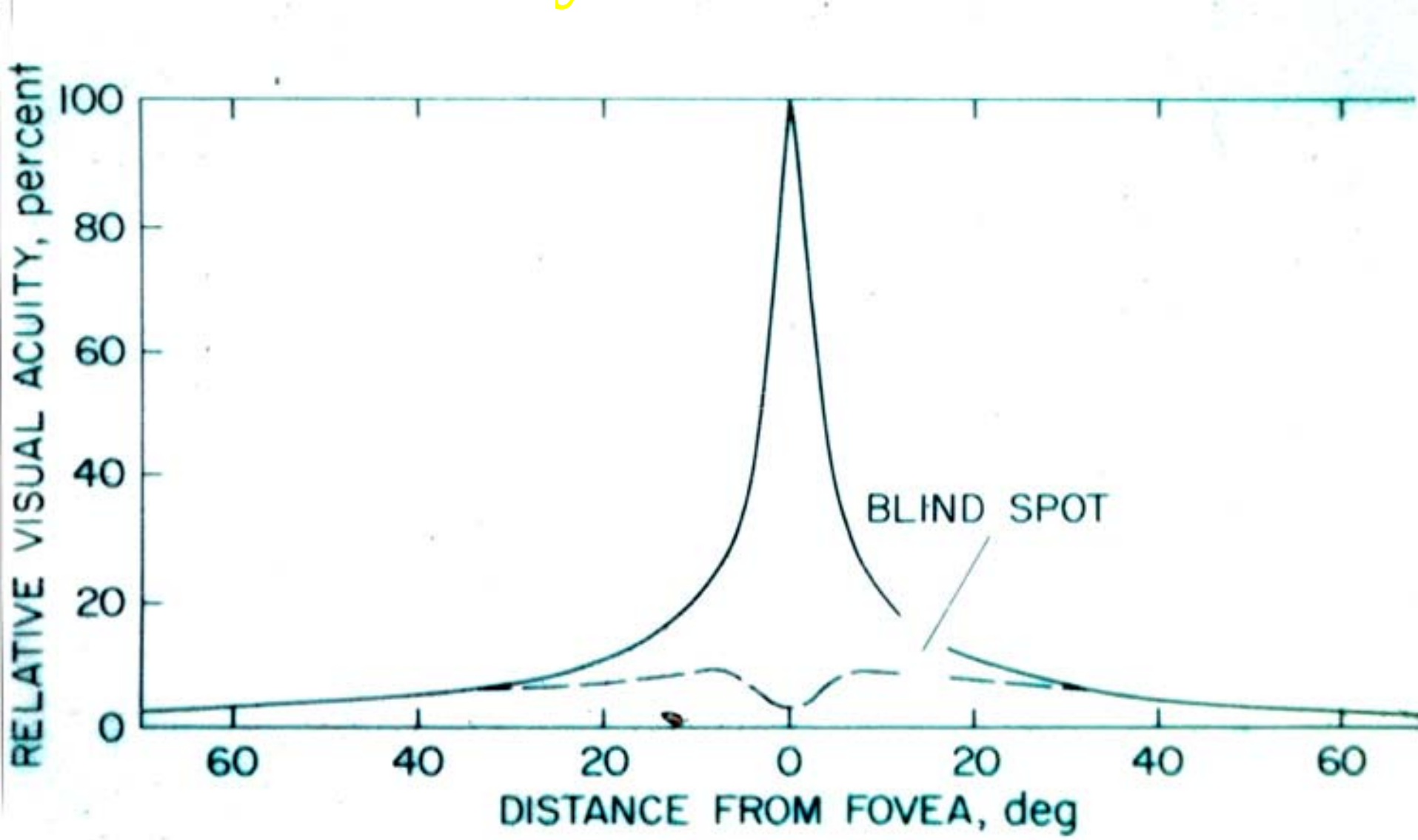
The minimal retinal image size: diffraction

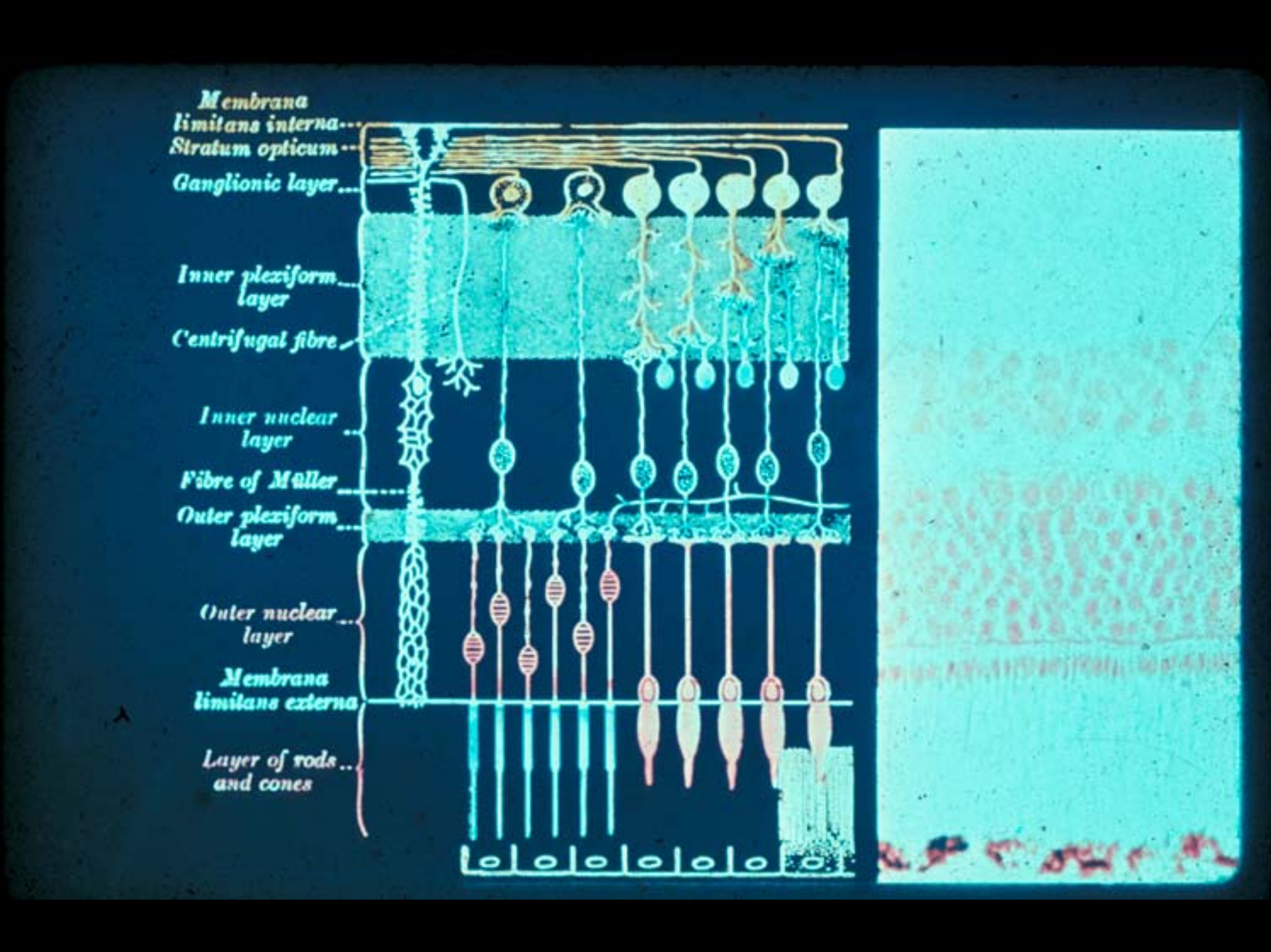


Off-Axis Retinal Exposure

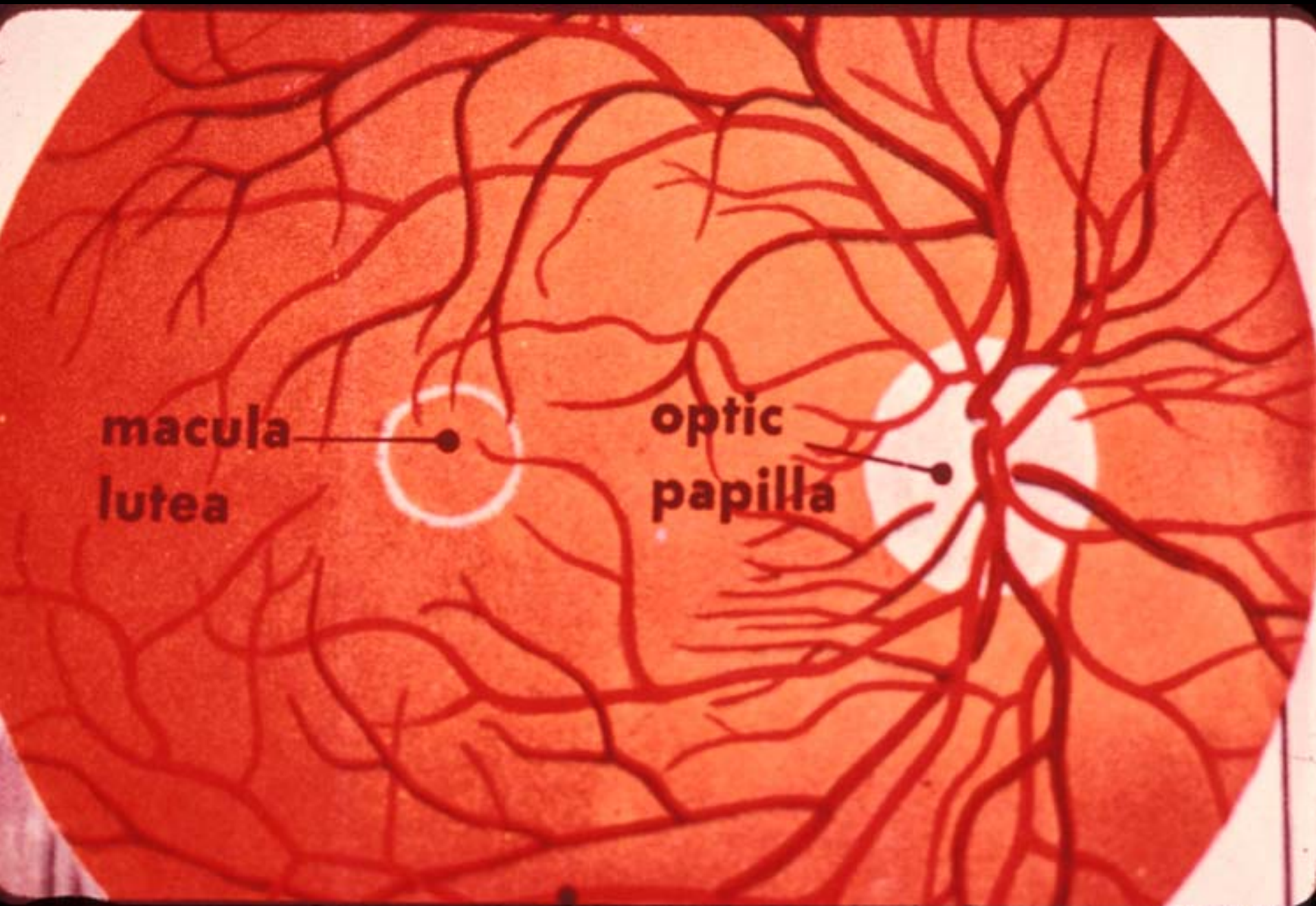


Visual Acuity Decreases Off-Axis

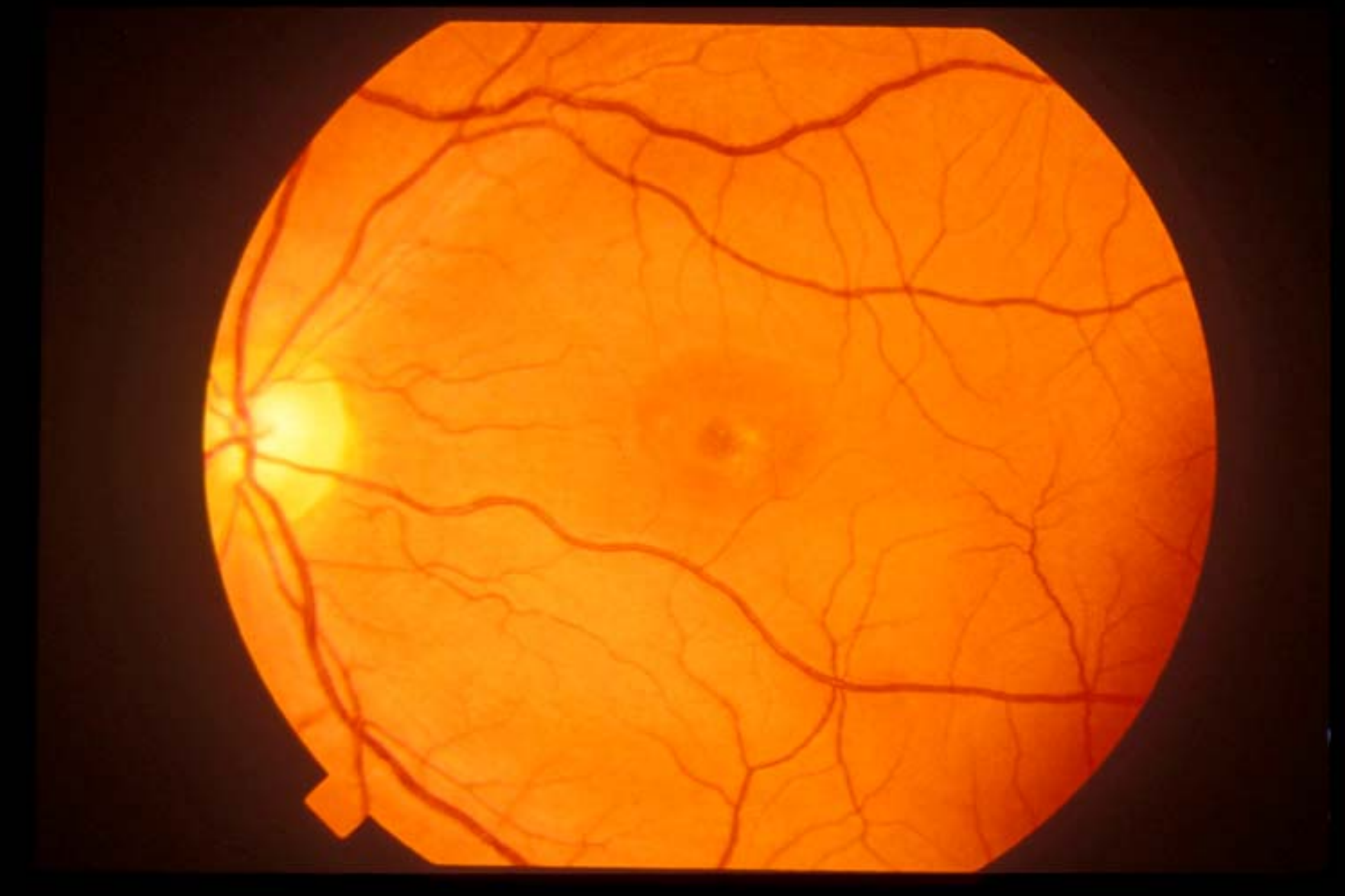


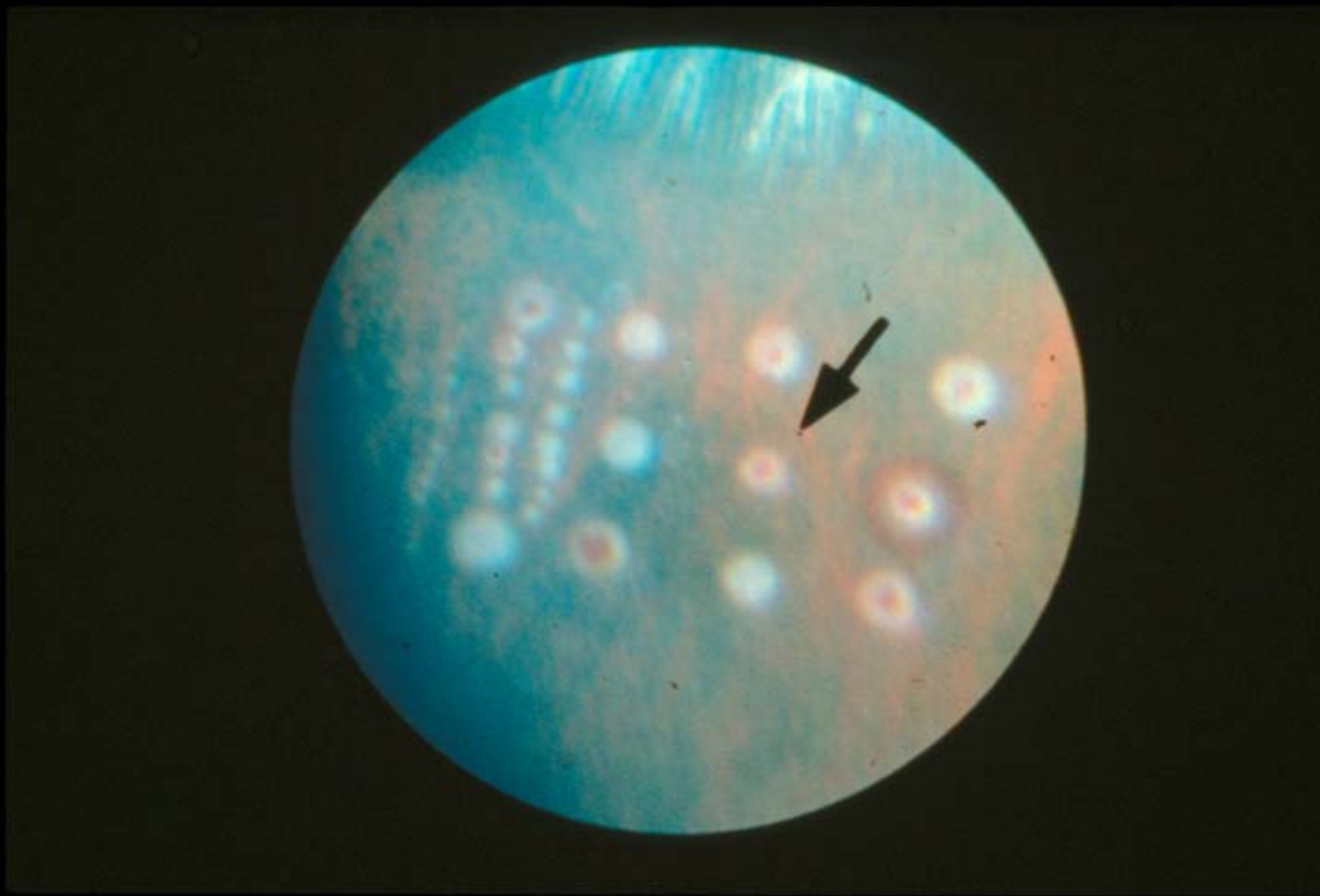

Membrana limitans interna
Stratum opticum
Ganglionic layer
Inner plexiform layer
Centrifugal fibre
Inner nuclear layer
Fibre of Müller
Outer plexiform layer
Outer nuclear layer
Membrana limitans externa
Layer of rods and cones

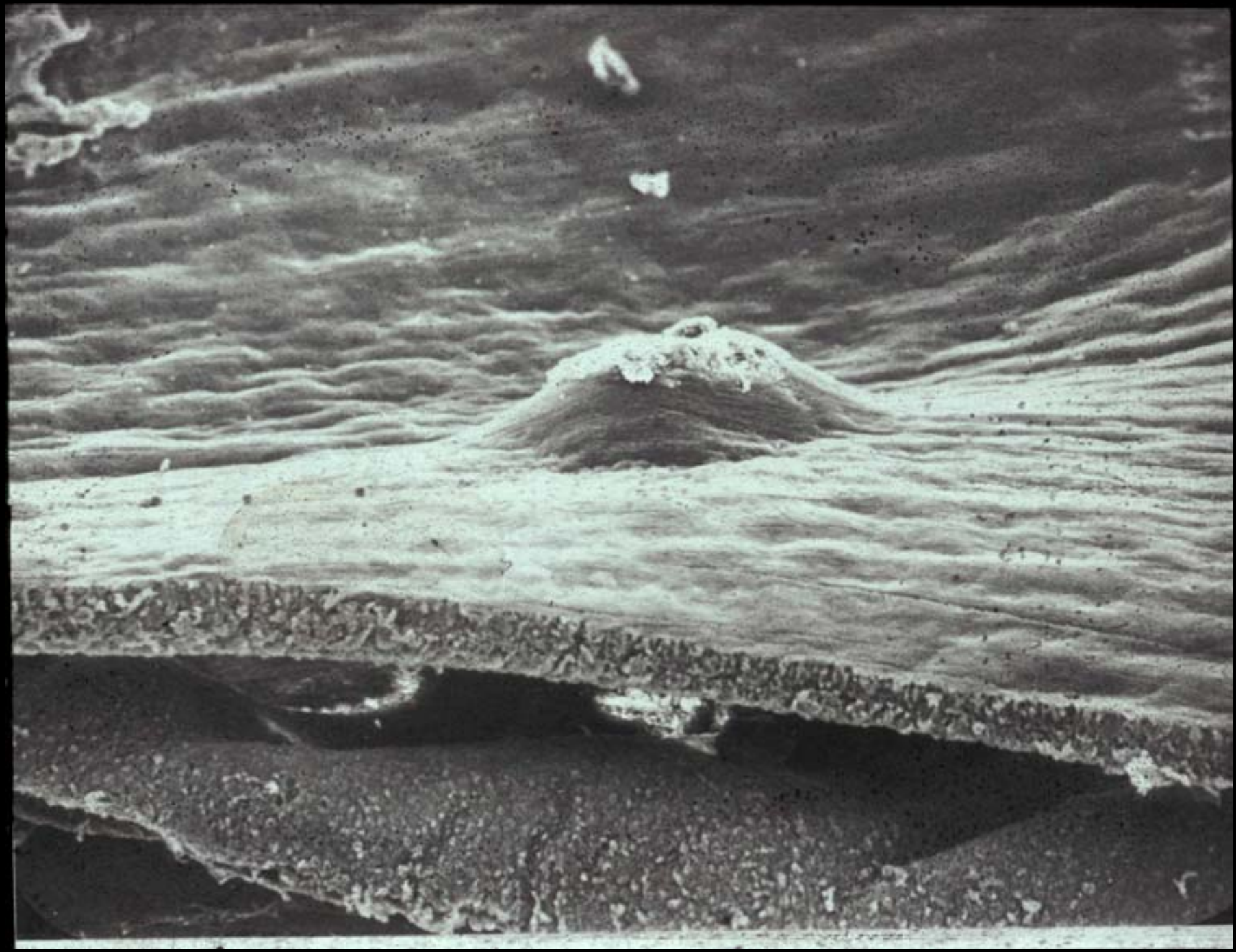
The Ocular Fundus



Photic maculopathy—welding arc



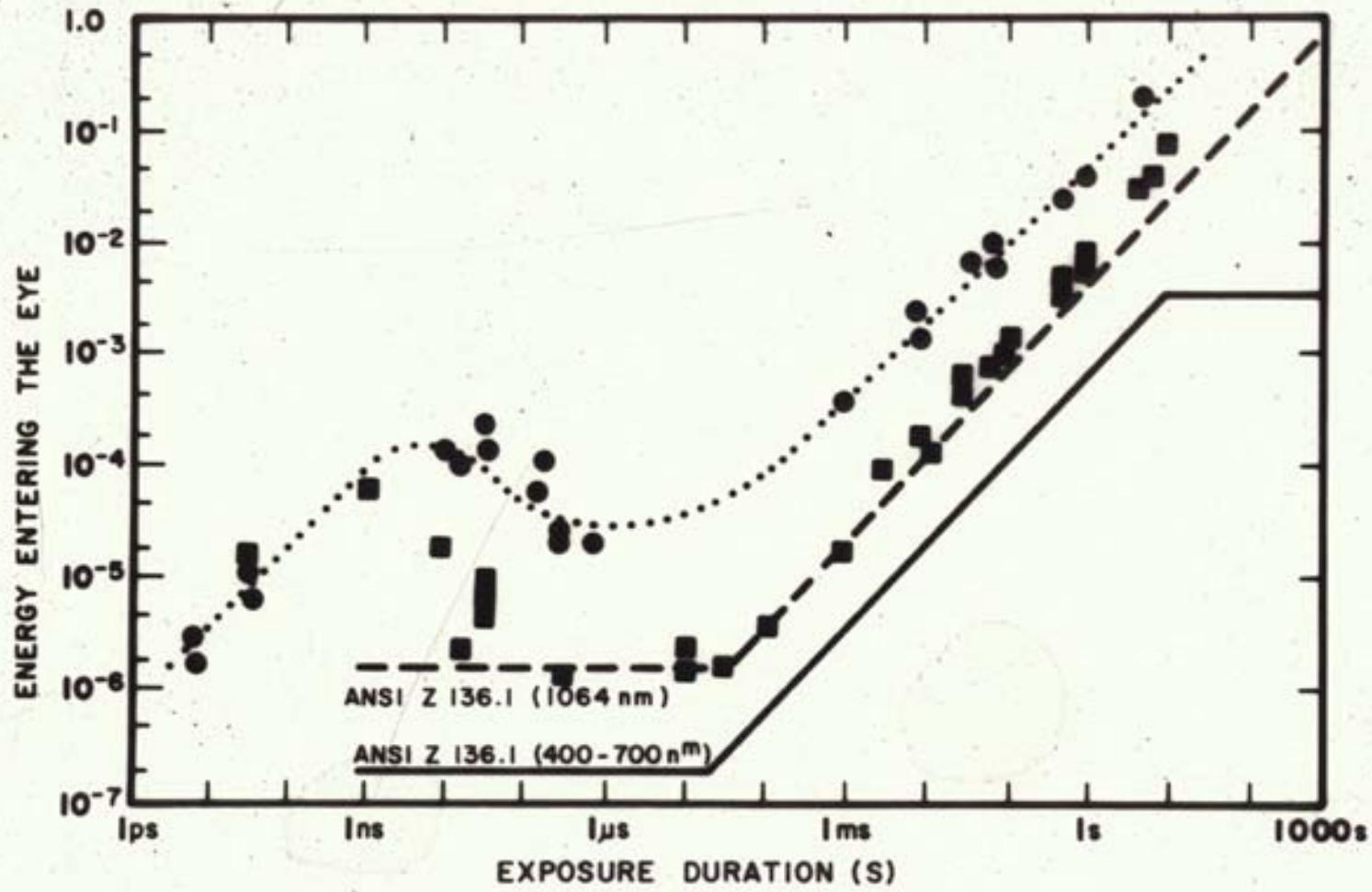




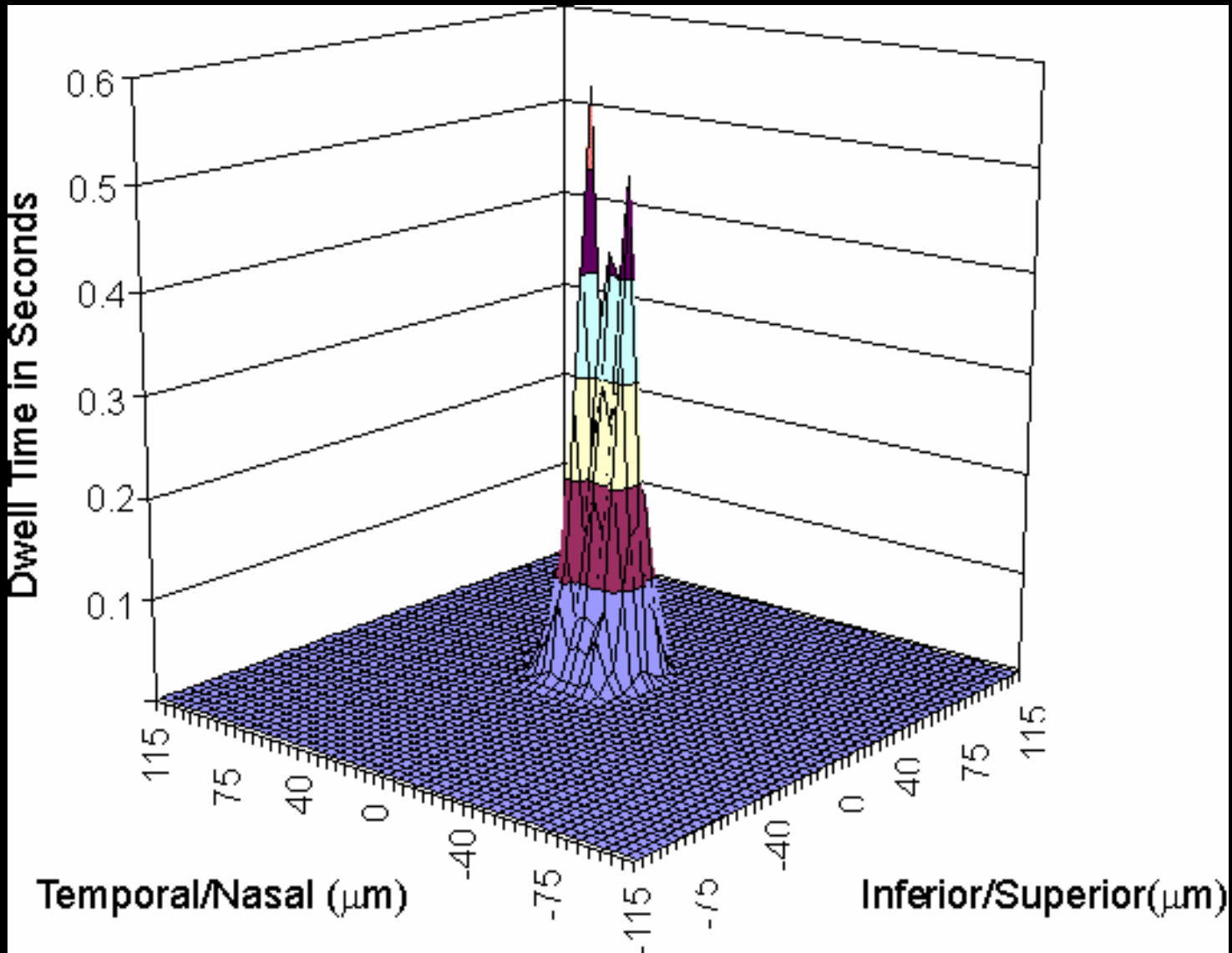
Energy Levels Known to Produce Retinal Injury

- Ruby 649.3 nm
  - Visible Lesion
    - 10 μJ into eye
  - Suprathreshold Lesion
    - 240 μJ into eye
- Neodymium: YAG 1064 nm
  - Visible Lesion
    - 28 μJ into eye
  - Suprathreshold Lesion
    - 1 mJ into eye

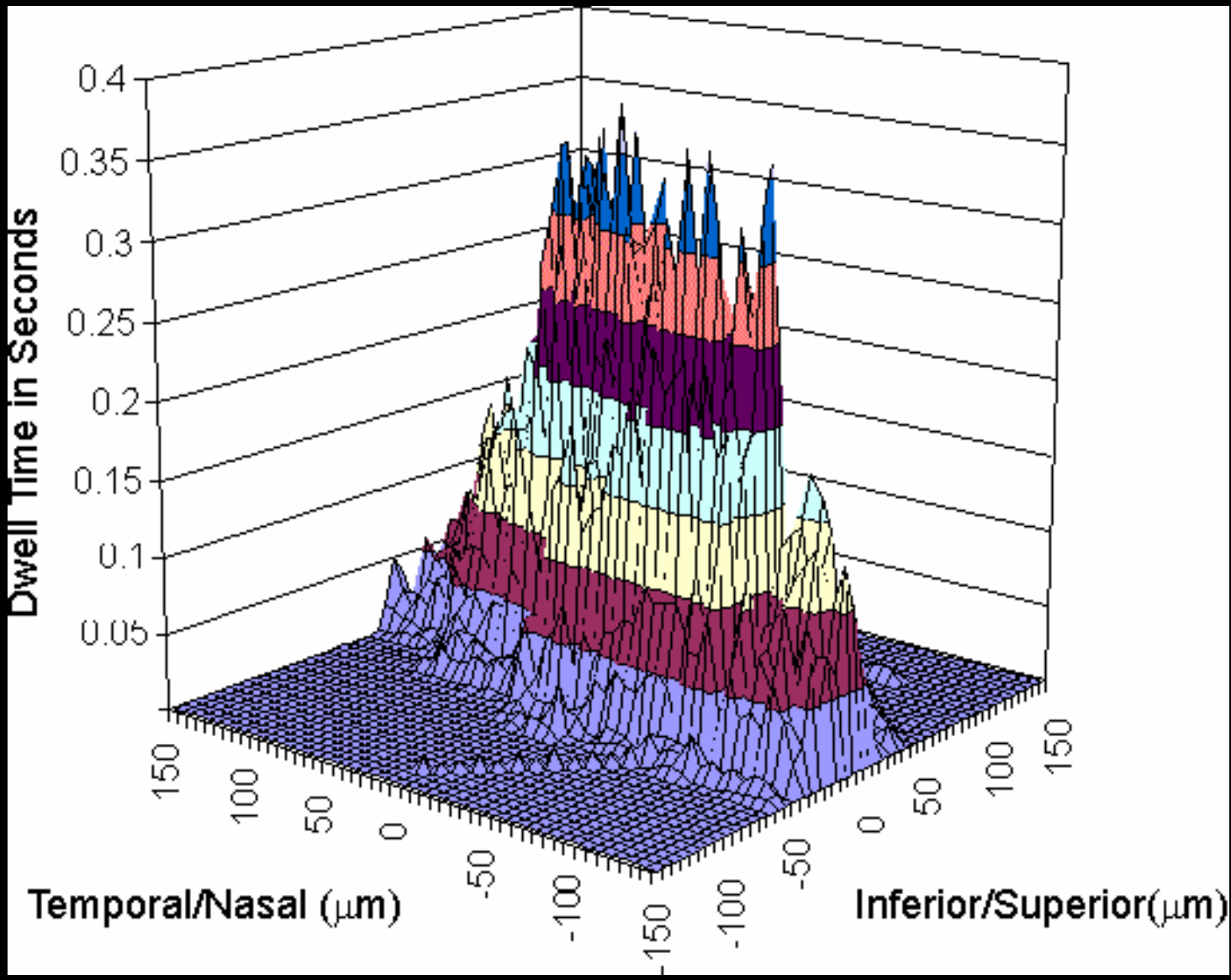
Retinal Injury Thresholds as Energy



Eye Movements: 1-second Fixation

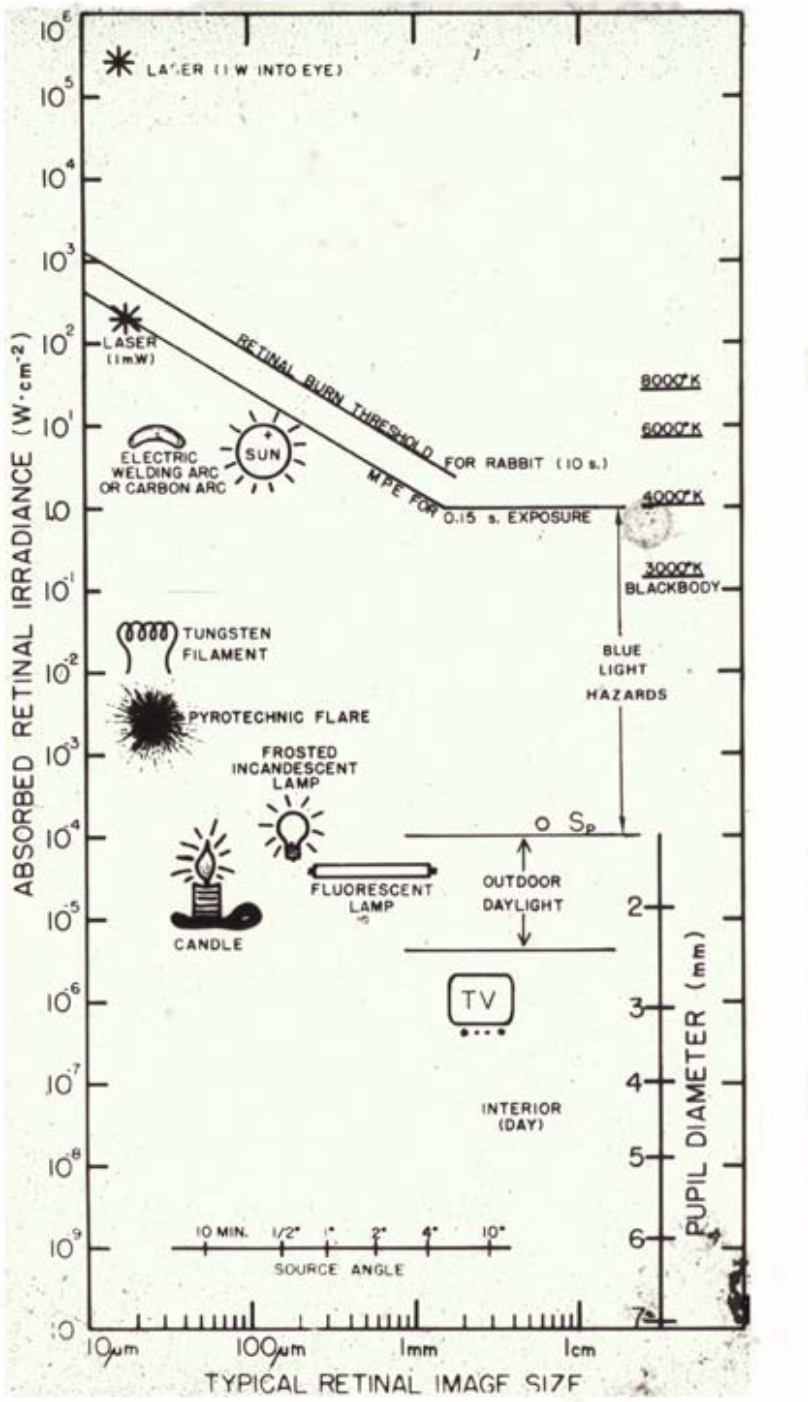


Eye Movements: 100-second Fixation



Retinal Illumination

- The ambient outdoor illumination of the retina is of the order of 0.02-0.1 mW/cm^2 and these levels are just comfortable to view
- The sun's image is a million times greater



Medical Surveillance: Vision Tests of Laser Workers

- ANSI Z136.1-2000 recommends vision tests (visual acuity, color chart and Amsler Grid) -- similar to a drivers' license vision test prior to work.
- This recommendation was based upon the assumption that workers are exposed to retinal-hazard wavelengths!
- The 2006 Revision will relax these rules

Medical Surveillance: In case of an accident

- If an injury occurs or a possibly injurious exposure is even suspected:
- THEN: Complete eye examination by an ophthalmologist should take place.
- For corneal injuries: healing within 24-48 hours should result without any treatments.
- Retinal injuries from visible and near-infrared lasers pose a more serious problem.

Explaining Laser Technology can be difficult sometimes

- Any sufficiently advanced technology is indistinguishable from magic!

  —-- Arthur C. Clarke

- Laser workers sensitized to eye hazards may think that a change of vision may have resulted from laser work. How do you know?

If we are effective in heightening the laser worker's concern….

- Hopefully we are effective in our laser safety training program and heighten the laser worker's concern about eye hazards
- The *corollary* may be that the worker may suspect any change in vision or any ocular disease as be related to laser work, even when it cannot be connected to work

Medical Surveillance of Laser Workers

- The original medical surveillance protocols date back to the early 1960s when occupational physicians were concerned that there could be biological effects of laser radiation that were not fully understood.

- Early programs emphasized routine retinal examinations to search for any possible changes.

Post-Incident Exposure Exams

- Medical exam requirements have been continuously reduced in scope and detail since the 1960s.
- Tests of visual function are now emphasized.
- The remaining requirements for medical surveillance in ANSI Z136.1-2000 require detailed eye examinations (e.g., fundus examinations) only after an incident.

Accidental Laser Exposures

- A laser incident can result from accidental ocular exposure to a hazardous beam with the result of an obvious injury.
- It can also result from exposure to a bright light which surprises the individual and the self-examine their vision with the result that they think they may have been injured.
- But, is it light damage?

But is it laser or light damage, or…..?

The tiny spots may be:

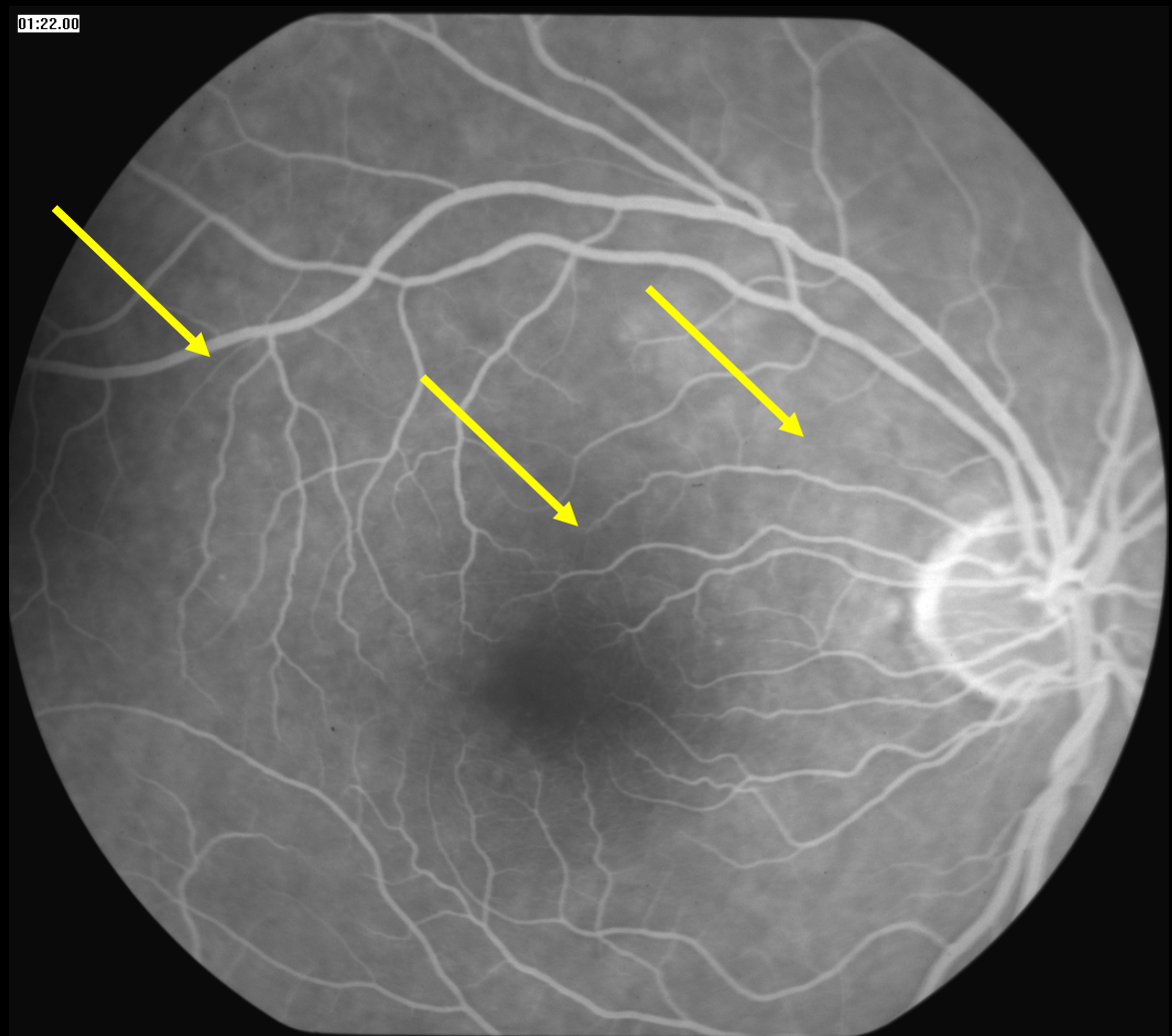
- "window defects
- "flecks"
- "drusen"
- Etc.

A retinal fundus photograph frequently will show tiny spots

Fluorescein Angiograms

Examples of small “window defects” in the RPE

Three Small Window Defects in a Fluorescein Angiogram…….



Proving the Negative

- One cannot prove the null hypothesis.

- "When a scientist says something is possible, he is probably right.
- When he says something is impossible, he is probably wrong."
- --Arthur C. Clarke

Conclusions

- Lasers pose special problems where the beam is collimated and the hazard can exist at considerable distance
- Low probability of exposure, but severe eye injury could result
- Safety standards emphasize control measures that correspond to hazard classes
- Training is a key element of any laser safety program